Missouri Department of Natural Resources Water Protection Program

Total Maximum Daily Loads (TMDL)

for

Marmaton River

Vernon County, Missouri

Completed: October 18, 2010
Approved: October 26, 2010

Total Maximum Daily Loads (TMDL)
For Marmaton River
Pollutant: Low Dissolved Oxygen

Name: Marmaton River

Location: Near Nevada in Vernon County, Missouri

Hydrologic Unit Code: 10290104

Water Body Identification: 1308

Missouri Stream Class: P[1]

Designated Beneficial Uses:
- Irrigation
- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B

Location of Impaired Segment: Section 19, T38N, R29W to Kansas state line

Length of Impaired Segment[2]: 49.5 miles

Use that is impaired: Protection of Warm Water Aquatic Life

Pollutant: Low Dissolved Oxygen

TMDL Priority Ranking: High

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[1] Class P streams are streams that maintain permanent flow even during drought conditions. See the Missouri Water Quality Standards at 10 Code of State Regulations 20-7.031(1)(F)4. The water quality standards can be found at: www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf

[2] Listed as impaired on the 2008 303(d) List for the full classified water body length of 49.5 miles. The length of the water body segment has been revised in 10 CSR 20-7.031 Table H to 35.7 miles, effective October 2009. The revised location is Section 11, T37N, R31W to Kansas state line This revision reflects location and length of the Marmaton River as it appears in the National Hydrography Dataset created by the U.S. Geological Survey. Revisions to 10 CSR 20-7.031 have not been approved by the U.S. Environmental Protection Agency at the time of TMDL submittal.

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1 Introduction

The Marmaton River Total Maximum Daily Load, or TMDL, is being established in accordance with Section 303(d) of the federal Clean Water Act. This water quality limited segment near Nevada in Vernon County, Mo. is included on the U.S. Environmental Protection Agency, or EPA, approved Missouri 2008 303(d) List of impaired waters.

The purpose of a TMDL is to determine the pollutant loading that a water body can assimilate without exceeding the water quality standards for that pollutant. Water quality standards are benchmarks used to assess the quality of rivers and lakes. The TMDL also establishes the pollutant load capacity necessary to meet the Missouri water quality standards established for each water body based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload allocation, a load allocation and a margin of safety. The wasteload allocation is the portion of the allowable pollutant load that is allocated to point sources. The load allocation is the portion of the allowable pollutant load that is allocated to nonpoint sources. The margin of safety accounts for the uncertainty associated with the model assumptions and data limitations.

The Marmaton River was first placed on Missouri's 303(d) List of impaired waters in 1998 by EPA, citing "natural background" conditions. The impairment was changed to low dissolved oxygen on the 2002 303(d) List, with the source of the impairment unidentified. The Marmaton River is currently on the EPA-approved 2008 303(d) List for not meeting the minimum dissolved oxygen criterion of 5 milligrams per liter, or mg/L, for the entire length of its class P segment. A two mile segment of the Marmaton River downstream of the Kansas-Missouri state line appears on the Missouri 2008 303(d) List as impaired by the Fort Scott Wastewater Treatment Plant (WWTP). The source of impairment for the remainder of the Marmaton River is still unidentified. It should be noted the Ft. Scott WWTP recently completed significant upgrades to its wastewater treatment processes. Future Missouri 303(d) List assessments will determine whether this facility is still the source of the impairment in the two mile segment downstream from the Kansas-Missouri state line. Future assessments will also attempt to determine the nature and source of the impairment on the remainder of the Class P segment.

A major tributary to the Marmaton River is Little Drywood Creek. Little Drywood Creek is also currently on the EPA-approved 2008 303(d) List for not meeting the minimum dissolved oxygen criterion, and a TMDL will be developed for Little Drywood Creek at a later date.

The Marmaton River has also appeared on the Kansas 303(d) List of impaired waters since at least 1998, where it was listed for violation of the state's water quality criterion for dissolved oxygen. TMDLs to address dissolved oxygen and biological impairments have been completed by Kansas for the portion of the Marmaton River watershed in that state. Other impairments for ammonia and bacteria have been cited as resolved on the Kansas 2010 303(d) List, and the Marmaton River is currently not listed as impaired and requiring a TMDL in Kansas.

2 Background

This section of the report provides information on the Marmaton River and its watershed.

2.1 The Setting

The Marmaton River originates in Allen County, Kan., and flows in an easterly direction through Bourbon County, and then into Vernon County, Mo. The Marmaton River watershed also includes part of Crawford County, Kan., and Barton County, Mo. The Marmaton River is a major tributary to the Little Osage River and joins the Little Osage just north of the city of Nevada, Mo. The main stem of the Marmaton River flows for roughly 66 miles through Kansas, where it drains a watershed of approximately 613 square miles. Once in Missouri, the river flows for approximately another 36 miles, with a watershed in this state of approximately 535 square miles. Altogether, the Marmaton River is 102 miles long and drains a watershed of 1,148 square miles in both Kansas and Missouri (Figure 1).

The impaired length of the Marmaton River in Missouri is 35.7 miles, the full length of the class P segment for this water body (see footnote 2 on page ii). The classified segment corresponds to that portion of the stream defined in Missouri's water quality standards (10 CSR 20-7.031 Table H); the impaired segment corresponds to that portion of the stream determined to not be meeting water quality standards. In this case, the length of the classified segment and impaired segment are the same. (Missouri Secretary of State 2009)

2.2 Population

Based on spatial analysis performed by the Missouri Department of Natural Resources, or the department, using 2000 census data, the population of the entire Marmaton River watershed is approximately 35,863. This equates to an average population density of approximately 31 persons per square mile (U.S. Census Bureau 2001). In the Missouri portion of the watershed, the total population is 18,309, with an average population density of 34 persons per square mile. The overall population in Missouri is predominantly rural, with a number of small towns scattered throughout. However, the populated portion of the watershed is dominated by the city of Nevada which, at a population of 8,607, accounts for nearly half of the people living in the watershed (U.S. Census Bureau 2000).

The Kansas portion of the Marmaton River watershed can similarly be characterized as predominantly rural. Data from the 2000 Census indicates the population in the Kansas portion of the watershed is 17,558, with an average population density of 29 persons per square mile. Like Missouri, nearly half of the people in the watershed live in a single urban center, Fort Scott, with a population of 8,297 (U.S. Census Bureau 2000 and 2002).

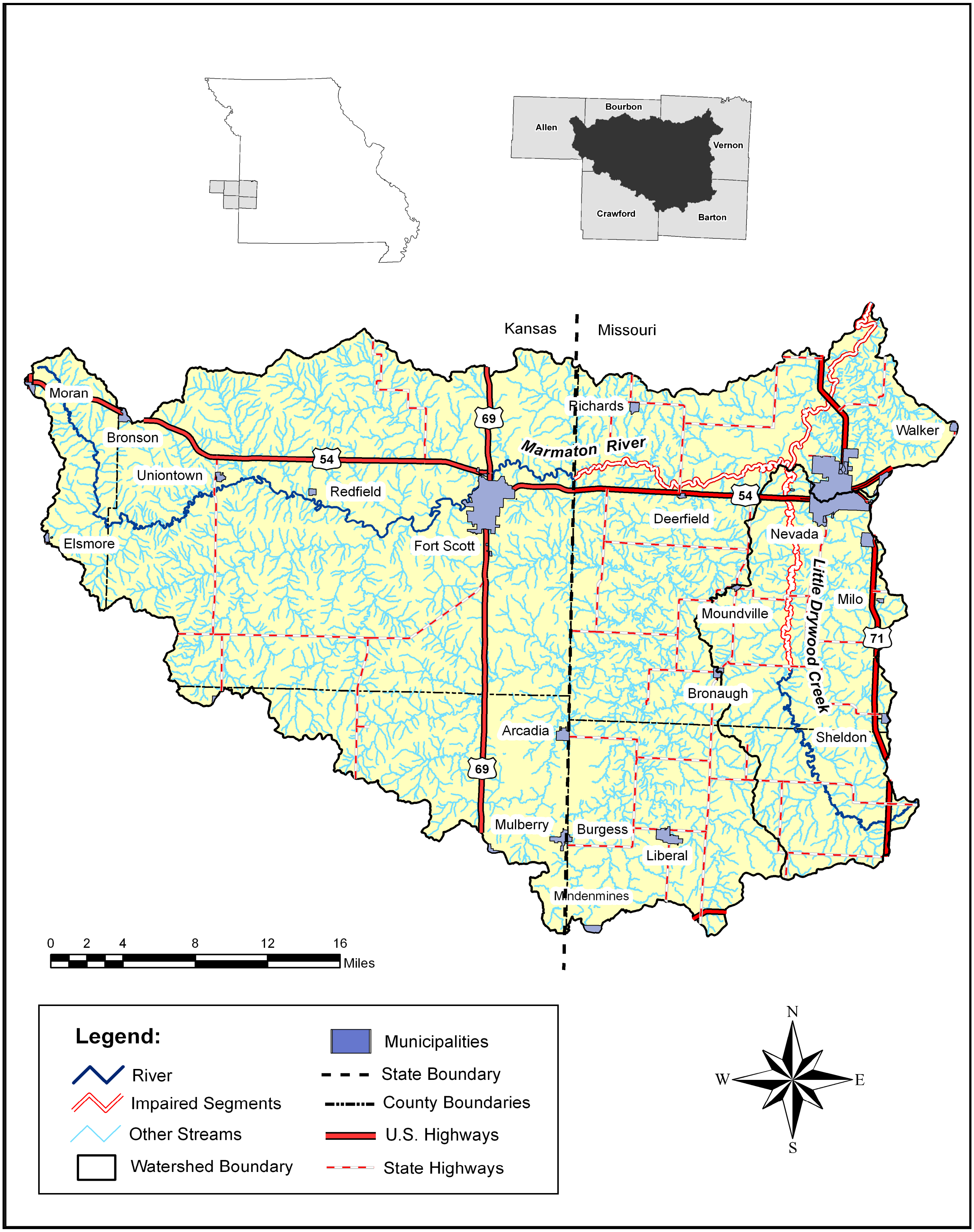

Figure 1. Location of the Marmaton River watershed (MoRAP 2005 and KARS 2008)

2.3 Geology, Physiography and Soils

The Marmaton River watershed in Missouri ranges in elevation from 720 to 1,020 feet, with slopes ranging from level in the extensive stream bottoms to gently sloping in the adjacent upland areas. Throughout other parts of the watershed, slopes range from moderate to steep. Elevations and topographic relief generally increase as the watershed extends west into Kansas. This region is unglaciated and the entire basin is dominated by Pennsylvanian-age bedrock, with alternating deposits of sandstone, shale and limestone.

The watershed associated with the lower portion of the Marmaton, from about the Kansas-Missouri state line to the confluence with the Little Osage River in Missouri, falls within the Cherokee Plains ecoregion. This area is characterized by relatively flat erosional plains with claypan soils that are less fertile and more poorly drained than soils in the adjacent Wooded Osage Plains ecoregion. Wide alluvial valleys with abundant wetlands exist in an area that saw presettlement vegetation of both upland and wet prairie, and oak-hickory woodlands. The Wooded Osage Plains ecoregion dominates the central portion of the watershed around Fort Scott. This region is characterized by gently rolling upland prairie broken by low limestone escarpments. Although the stream valleys are relatively wide, there is greater topographic relief here – particularly in the escarpment zones – than in the Cherokee Plains. Presettlement vegetation was a mixture of oak-hickory woodlands and bluestem prairie. The Osage Cuestas ecoregion dominates the western portion of the watershed and offers still greater topographic relief, along with a transition from grassland and prairie in the western part of the region to oak-hickory forests in the east (Chapman, *et al*. 2001 and 2002).

The Soil Survey Geographic database developed by the U.S. Department of Agriculture Natural Resources Conservation Service, or NRCS, shows that greater than 89 percent of the soils in the Marmaton River watershed in Missouri are characterized as having slow or very slow infiltration rates, and roughly 30 percent of the land area is considered highly erodible or potentially highly erodible. (NRCS 2006 and 2007). Soil groups are represented primarily by Barden and Parsons silt loams, and Barco loam on the hillsides and uplands, ranging from somewhat poorly to moderately well drained. Osage silty clay makes up the dominant soil group on the mostly level and poorly drained floodplains of the Marmaton River (USDA 1977).

According to the Kansas TMDL for the Marmaton River subbasin of the Marais des Cygnes River watershed, average soil permeability within the Marmaton River watershed in that state is 0.9 inches per hour (based on the NRCS State Soil Geographic database). Furthermore, greater than 99 percent of the watershed produces runoff under relatively low potential conditions of 1.71 inches per hour. Storms generating less than 0.57 inches per hour generate runoff from over half the watershed, primarily in the lower two-thirds of the watershed and along the stream channels (Kansas Department of Health and Environment 2001).

2.4 Land Use and Land Cover

The land use and land cover of the Marmaton River watershed is summarized by state in Table 1 and shown in Figure 2. The primary land uses for the entire watershed are grassland (57 percent), cropland (21 percent) and forest and woodland (12 percent) with open water and urban areas occupying 1.2 and 2.2 percent of the watershed area, respectively. Roughly 8 percent of the watershed in Missouri is classified as wetland. The land use map in Figure 2 indicates that the majority of these are riparian and floodplain wetlands associated with Drywood Creek, Little Drywood Creek, and along the Marmaton River downstream of these two tributaries.

Table 1. Land use/land cover in the Marmaton River watershed (MoRAP 2005 and KARS 2008).

Land Use/ Land Cover	Missouri			Kansas			Entire Watershed		
	Watershed Area			Watershed Area			Watershed Area		
	Acres	Square Miles	Percent	Acres	Square Miles	Percent	Acres	Square Miles	Percent
Urban	9609	15.0	2.8	6510	10.2	1.7	16119	25.2	2.2
Cropland	103390	161.6	30.2	54254	84.8	13.8	157644	246.3	21.5
Grassland	159911	249.8	46.7	260409	406.9	66.4	420320	656.8	57.2
Forest/Woodland	24995	39.1	7.3	66547	104.0	17.0	91542	143.0	12.5
Open Water	5077	7.9	1.5	3951	6.2	1.0	9028	14.1	1.2
Barren	862	1.3	0.3	416	0.6	0.1	1277	2.0	0.2
Herbaceous	10562	16.5	3.1	ND	ND	ND	10562	16.5	1.4
Wetland	27872	43.6	8.1	ND	ND	ND	27872	43.6	3.8
Total	342278	534.8	100	392087	612.7	100	734364	1147.5	100

Note: MoRAP = Missouri Resource Assessment Partnership
KARS = Kansas Applied Remote Sensing Program
ND = No Data. At the time of this TMDL, no data were available to estimate area of herbaceous and wetland land cover in Kansas.

When considering land use, it should also be noted that there are a number of surface water impoundments affecting a sizable portion of the watershed. The total land area regulated by impoundments is 134 square miles, or 11.7 percent of the watershed. Of this area, 106 square miles are in Kansas, which amounts to roughly one-quarter of the watershed in that state. Additional proposed impoundments would, if built, increase the total regulated drainage area to 67 percent of the watershed in Kansas, and 28 percent of the watershed as a whole (Heimann, et al., 2007).

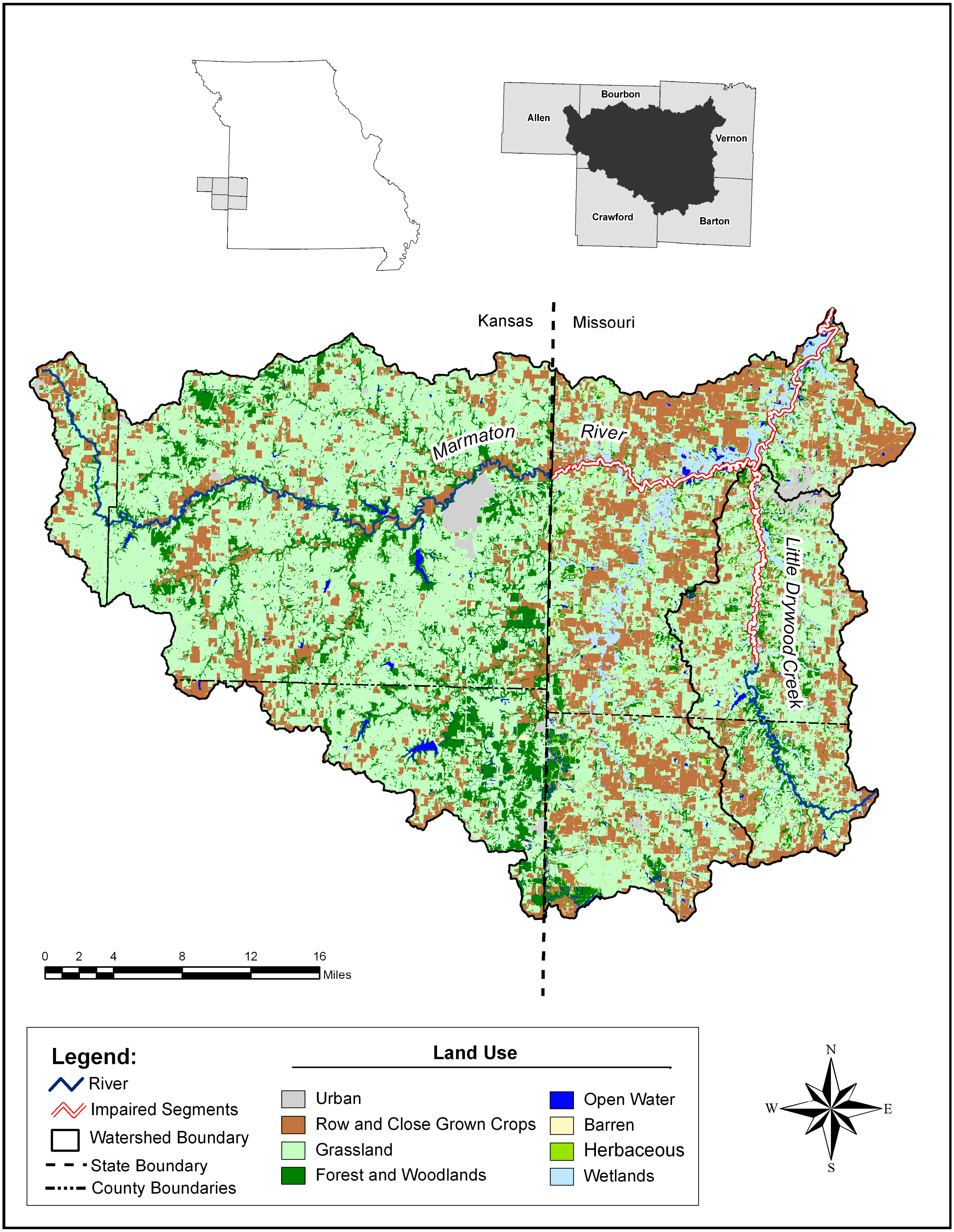

Figure 2. Land use/land cover in the Marmaton River watershed (MoRAP 2005 and KARS 2008)

2.5 Defining the Problem

A TMDL is needed for the Marmaton River because it is not meeting the water quality criterion for dissolved oxygen. Low dissolved oxygen is an issue because concentrations have been measured at less than the minimum water quality criterion of 5 mg/L.

Water from the Marmaton River downstream of the Fort Scott wastewater treatment plant was sampled and analyzed by the Kansas Department of Health and Environment, or KDHE. Data from this site is considered representative of water quality in Missouri near the state line, and these data are of sufficient quality to be used by the Missouri Department of Natural Resources for the purposes of evaluating compliance with Missouri water quality standards and to support TMDL development. Twelve of 34 dissolved oxygen measurements taken at this site between 2001 and 2006 failed to meet Missouri's minimum dissolved oxygen criterion of 5 mg/L. There have been no dissolved oxygen samples below 5 mg/L recorded since November 2006. Data used in the assessment of the dissolved oxygen impairment are presented in Appendix A.1.

Water from several sites along Little Drywood Creek was sampled and analyzed by the department and others between 2003 and 2008. These data are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development. The dissolved oxygen results for these surveys are summarized in Table 2 and indicate a 63 percent frequency of exceedance of the dissolved oxygen criterion of 5 mg/L. Data used in the assessment of the dissolved oxygen impairment are presented in Appendix A.2.

Table 2. Summary of dissolved oxygen data for Little Drywood Creek.

Organization	Site Name	From	To	No. of samples	No. of samples <5 mg/L	Percent of samples <5 mg/L
MoDNR	3-5.5 miles SW Nevada	2003	2007	7	3	42.9
MoDNR	at State Highway N	7/15/2008	7/28/2008	1419	89	6.3
ERC	at State Highway N	7/18/2007	8/7/2007	2019	671	33.2
ERC	at State Highway F	7/31/2006	8/14/2006	1336	1273	95.3
ERC	at State Highway F	8/8/2007	8/23/2007	1428	1428	100
MoDNR	5 miles SW of Nevada	7/30/2008	8/26/2008	2551	548	21.5
ERC	5 miles SW of Nevada	8/14/2006	9/13/2006	2864	2864	100
ERC	5 miles SW of Nevada	8/23/2007	9/4/2007	1154	1153	99.9
Total				12778	8029	62.835

MoDNR = Missouri Department of Natural Resources
ERC = Environmental Resources Coalition (Data collected by MEC Water Resources under contract.)

As discussed further in Section 4 of this document, the low dissolved oxygen problem could be due to one or more of the following:

- Excessive loads of decaying organic solids, as measured by biochemical oxygen demand.
- Too much algae in the stream as a result of excessive phosphorus or nitrogen loading.
- High consumption of oxygen from decaying matter on the streambed.
- Physical factors associated with low stream reaeration rates.

3 Source Inventory

This section summarizes the available information on significant sources of nutrients and oxygen-consuming substances in the Marmaton River watershed. Point (or regulated) sources are presented first, followed by nonpoint (or unregulated) sources.

3.1 Point Sources

The term "point source" refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the Missouri State Operating Permit program, and include municipal wastewater treatment facilities[3]. By law, point sources also include: concentrated animal feeding operations, or CAFOs, (which are places where animals are confined and maintained or fed); stormwater runoff from municipal separate storm sewer systems; and stormwater runoff from construction and industrial sites. All of the permitted facilities in the Missouri portion of the Marmaton River watershed are shown in Figure 3 and listed in Table 3.

[3] The Missouri State Operating Permit program is Missouri's program for administering the federal National Pollutant Discharge Elimination System program.

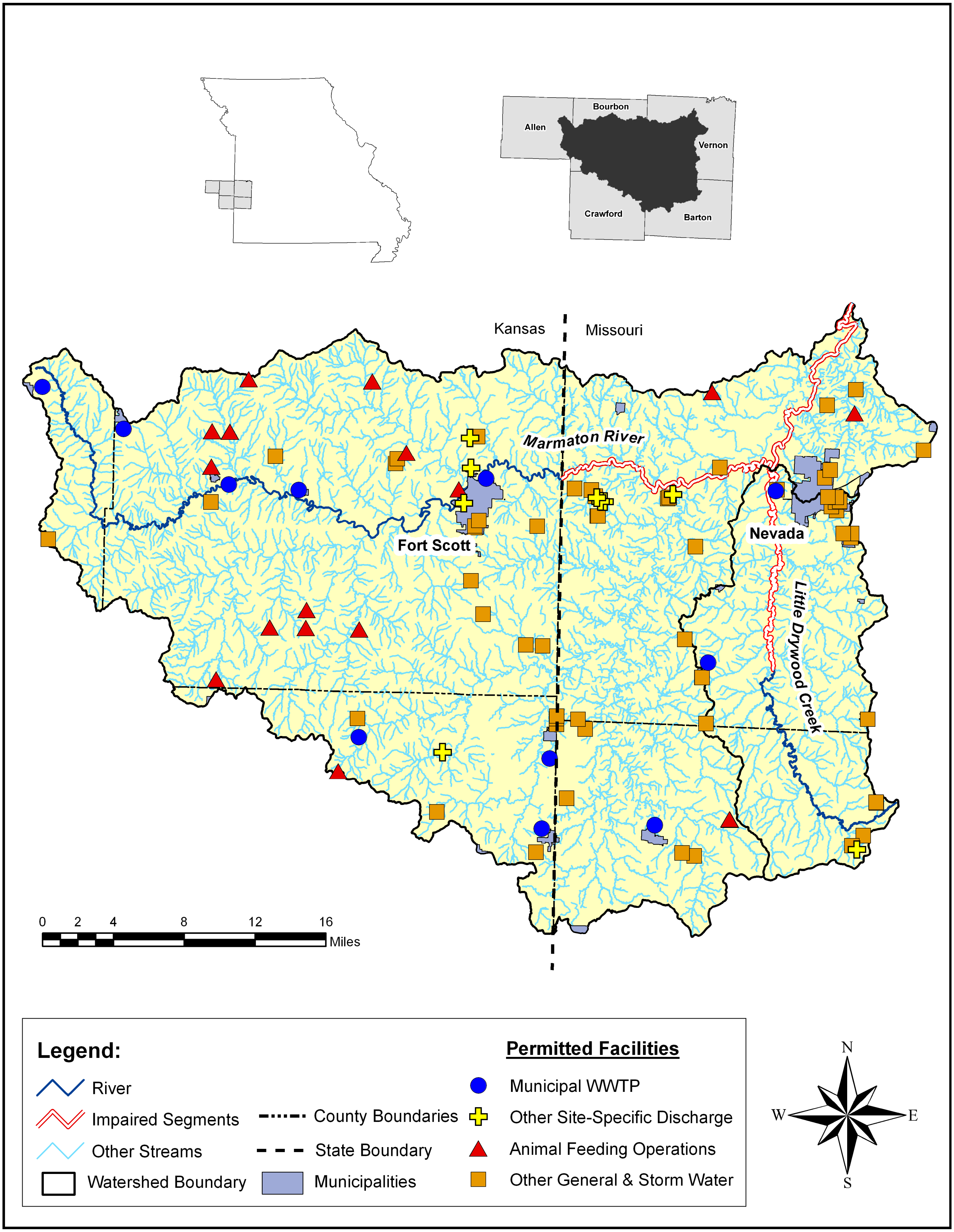

Figure 3. Location of permitted facilities in the Marmaton River watershed

Table 3. Missouri permitted facilities in the Marmaton River watershed.

Facility ID	Facility Name	Receiving Stream	Design Flow (MGD)	Permit Expiration Date
MO-0042153	Rolling Meadows Subdivision WWTP	Tributary Little Drywood Creek	0.024	07/26/2011
MO-0045837	Liberal Municipal WWTP	Bitter Creek	0.2	07/12/2010
MO-0089109	Nevada WWTP	Little Drywood Creek	1.75[4]	08/05/2009
MO-0109827	Emery Truck Plaza WWTP	Drywood Creek	0.008	10/31/2007
MO-0111082	3M Commercial Graphics	Tributary Willow Branch	(Rainfall dependent)	03/18/2014
MO-0120472	Bronaugh WWTP	Tributary Little Drywood Creek	0.0265	06/15/2009
MO-0121045	Prairie View Regional Waste Facility	Tributary Little Drywood Creek	8.7	01/19/2015
MO-0134139	Prairie Pride, Inc.	Tributary Green Branch	1.552[5]	01/24/2013
MO-G010412	Terry Koehn	Old Town Branch	0.00139	02/23/2011
MO-G010447	First Class Swine	Tributary E. Fork Drywood Creek	0.00075	02/23/2011
MO-G010510	Forkner Farms Swine Facility	Douglas Branch	0.0118	02/23/2011
MO-G050038	AFI 1991-02 & 1990-01 Reclamation Project	Tributary Drywood Creek	General Permit	03/02/2011
MO-G350159	MFA Bulk Plant-Nevada	Tributary Willow Branch	General Permit	06/14/2012
MO-G490226	Palmer Limestone	Tributary Drywood Creek	General Permit	10/04/2006
MO-G490542	Crane Plumbing	Tributary White Branch	General Permit	10/05/2011
MO-G821141	Hillcrest Lanes	Tributary Little Drywood Creek	General Permit	10/04/2012
MO-G822160	Houghton Deer Processing	Tributary Marmaton River	General Permit	06/08/2011
MO-R108629	Prairie View Regional Waste Facility	Tributary Little Drywood Creek	Stormwater Permit	02/07/2012
MO-R109AC5	MFA Bulk Plant-Irwin	Tributary Little Clear Creek	Stormwater Permit	03/07/2012
MO-R109X04	Prairie Pride, Inc.	Tributary Grassy Run	Stormwater Permit	03/07/2012
MO-R109X29	Prairie Pride 8” pipeline	Tributary Grassy Run	Stormwater Permit	03/07/2012

[4] Current permitted design flow. Proposed design flow in draft construction permit is 2.0 MGD.
[5] Total design flow includes 0.07488 MGD non-stormwater design flow.

Facility ID	Facility Name	Receiving Stream	Design Flow (MGD)	Permit Expiration Date
MO-R10A720	Maxwell Farms of Missouri	Tributary E. Fork Drywood Creek	Stormwater Permit	02/07/2012
MO-R10A761	Wilson Turkey Farm	Tributary Hackberry Branch	Stormwater Permit	02/07/2012
MO-R10A831	City of Nevada WWTP	Hattons Slough	Stormwater Permit	02/07/2012
MO-R10A973	Maxwell Farms of Missouri	Tributary McKill Creek	Stormwater Permit	02/07/2012
MO-R10B369	MegWest Energy Missouri Corp.	Tributary Grassy Run	Stormwater Permit	02/07/2012
MO-R10B621	South Street Overpass Bridge	Tributary West Branch	Stormwater Permit	02/07/2012
MO-R10B842	MegWest Energy Missouri Corp.	Tributary Green Branch	Stormwater Permit	02/07/2012
MO-R10B866	Vernon County Sheriff's Office	Tributary Willow Branch	Stormwater Permit	02/07/2012
MO-R10C031	Massa Finisher	E. Fork Drywood Creek	Stormwater Permit	02/07/2012
MO-R10C160	MegWest Energy Missouri Corp.	Tributary Drywood Creek	Stormwater Permit	02/07/2012
MO-R10C262	Nevada Municipal Sports Complex	Tributary Drywood Creek	Stormwater Permit	02/07/2012
MO-R12A134	Murphy Farms Feed Mill	Tributary Sulphur Spring Branch	Stormwater Permit	07/27/2011
MO-R240031	Wilson's Plant Food	Tributary Old Town Branch	Stormwater Permit	02/19/2014
MO-R240123	Producer's Grain-Nevada	Tributary White Branch	Stormwater Permit	11/13/2008
MO-R240157	MFA Bulk Retail Plant-Irwin	Tributary Little Drywood Creek	Stormwater Permit	02/19/2014
MO-R240350	Hamersley Aerial Spray, Inc.	Tributary Old Town Branch	Stormwater Permit	02/19/2014
MO-R240363	Producer's Grain Company-Bronaugh	Tributary Drywood Creek	Stormwater Permit	02/19/2014
MO-R240451	Mid-West Fertilizer, Inc-Sheldon	Tributary Pleasant Creek	Stormwater Permit	02/19/2014
MO-R240452	Mid-West Fertilizer, Inc-Deerfield	Tributary Drywood Creek	Stormwater Permit	02/19/2014
MO-R240538	Farmers Ag & Grain-Deerfield	Tributary Drywood Creek	Stormwater Permit	11/13/2008
MO-R80H044	Young Iron and Metal, Inc.	Sulphur Spring Branch	Stormwater Permit	07/23/2014

Note: WWTP = Wastewater treatment plant

Although there are a number of permitted facilities within the Marmaton River watershed in Missouri, the Nevada Wastewater Treatment Plant, which discharges to Little Drywood Creek, has the largest non-stormwater permitted design flow. With an allowable discharge of 1.75 million gallons per day, out of a total for all facilities of 2.08 million gallons per day, the Nevada Wastewater Treatment Plant accounts for 84 percent of the total non-stormwater design flows shown in Table 4. Upon completion of the proposed facility expansion to 2.0 million gallons per day, this percentage will increase to 86 percent. The Nevada Wastewater Treatment Plant merits special attention because of its relative size and also because it discharges just upstream of where Little Drywood Creek joins the impaired segment of the Marmaton River. The facility currently consists of an oxidation ditch and a sludge holding basin, but is undergoing an upgrade and expansion to add four clarifiers, two aeration basins, two aerobic digesters and ultraviolet disinfection.

Like all wastewater treatment plants in Missouri, the Nevada Wastewater Treatment Plant must meet the requirements of an operating permit issued by the department. This permit contains discharge limits that the treatment plant must meet to be protective of instream water quality standards. The current permit expired in August 2009, but is still in effect pending issuance of a new permit. When a new operating permit is issued following the facility expansion, the permitted design flow will increase to 2.0 million gallons per day and the facility will be subject to revised effluent limitations and monitoring requirements.

The remaining sum of all non-stormwater permitted discharges into the Marmaton River watershed are contributed by three small wastewater treatment plants with lagoon systems and continuous discharge from one soybean biodiesel facility. These facilities have a combined non-stormwater design flow of 0.325 million gallons per day.

In addition to site-specific permits, there are a number of facilities with general permits, including stormwater permits, within the Marmaton River watershed in Missouri. General permits are issued to activities that are similar enough to be covered by a single set of requirements. Stormwater permits are issued to activities (e.g. land disturbance) that are similar enough to be covered by a single set of requirements and are expected to discharge in response to storm events. Both general and stormwater permits are meant to be flexible enough to allow for ease and speed of issuance while providing the required protection of water quality. Missouri general and stormwater permits within the Marmaton River watershed are identified by category in Table 4.

Since critical conditions for low dissolved oxygen occur during periods of low stream flow, it is unlikely that stormwater discharge from facilities with stormwater permits are a significant contributor to the low dissolved oxygen problem. It is also unlikely the general permits for land application of wastewater will contribute to the dissolved oxygen problem because these permits are no-discharge and contain restrictions designed to minimize the impact of land application to surface waters. Similarly, concentrated animal feeding operations are no-discharge except during storms exceeding the design storm event, and so are not likely to impact streams during critical periods of low flow. The other types of general permits within the Marmaton River watershed – those associated with petroleum facilities, limestone quarries and abandoned mine land reclamation– do allow both storm and non-stormwater discharge. However, these facilities are also required to adhere to operating conditions with the permits designed to minimize their impacts to surface waters. In addition, by the nature of their operations, discharge from these

facilities is unlikely to contain nutrients or oxygen-demanding substances that could contribute to the low dissolved oxygen impairment.

It should also be noted that all 11 municipalities located within, or partially within, the watershed in Missouri have populations under 10,000, and therefore are not required to obtain stormwater permits issued for municipal separate storm sewer systems.

Table 4. Categories of general and stormwater permits

Permit #	Description	Total
MO-G01xx	CAFO	3
MO-G05xx	Abandoned Mine Land Reclamation	1
MO-G35xx	Petroleum Storage	1
MO-G49xx	Limestone Quarries	2
MO-G821xx	Land Application Domestic WW Biosolids	1
MO-G822xx	Land Application Food Processing WW	1
MO-R10xx	Land Disturbance >1 Acre	11
MO-R108xx	Land Disturbance >1 Acre	1
MO-R109xx	Land Disturbance in Designated Areas	3
MO-R12Axx	Food and Kindred Products	1
MO-R240xx	Agrichemical Facilities	8
MO-R80Hxx	Solid Waste Transfer	1
	Total by watershed	**34**

Note: WW stands for wastewater.

While there are only three permitted concentrated animal feeding operations – one poultry and two swine facilities – in the Marmaton River watershed in Missouri, land use and agricultural statistics both indicate that livestock production is common in rural Barton and Vernon Counties (see Section 3.2 below). Animal feeding operations where animals are maintained or fed under confined conditions but which maintain fewer than 300 animal units are not legally defined as CAFOs under state regulations. Additionally, facilities that are defined as CAFOs but which maintain fewer than 1,000 animal units are not required to obtain a Missouri State Operating Permit. Since these operations are not regulated by the department, there is no data available on their numbers or locations. However, given the number of animals in both of these counties, it is possible that there are unregulated animal feeding operations within the Marmaton River watershed. Unregulated operations that do not properly manage livestock, and the waste that they produce, may potentially be acting as point source contributors to the low dissolved oxygen impairment.

The portion of the Marmaton River watershed within the state of Kansas contains eight permitted municipal wastewater dischargers. The Fort Scott Wastewater Treatment Plant is identified on the Missouri 2008 303(d) List as the source of the low dissolved oxygen impairment for a length of two miles downstream of the Kansas-Missouri state line. With the exception of Fort Scott, whose wastewater facility consists of a three-cell aerated lagoon system and a mechanical treatment plant with UV disinfection, each of these is a small lagoon-type facility with a low design flow. Information regarding these facilities, along with non-municipal permitted facilities

in Kansas, can be found in Table 5. Like Missouri, there are also no municipal separate storm sewer systems in the Kansas portion of the watershed. In addition to the municipal and non-municipal facilities, there are seven active livestock facilities within the watershed that are either certified or permitted by the State of Kansas. The total number of animal units[6] attributed to all known livestock facilities is 1,483. These facilities are listed in Table 6 and are also shown in Figure 3.

Illicit straight pipe discharges of household waste are also potential point sources in rural areas. These are discharges straight into streams or land areas and are different than illicitly connected sewers. There is no specific information on the number of illicit straight pipe discharges of household waste in the Marmaton River watershed.

Table 5. Kansas permitted facilities in the Marmaton River watershed.

Facility ID	Facility Name	Receiving Stream	Design Flow (MGD)	Permit Expiration Date
C-MC11-NO04	Country View Mobile Home Park	NA	No Discharge	Unknown
C-MC11-OO01	Fort Scott Campground	Marmaton River	0.00825	09/30/2009
C-MC11-OO03	Maple Ridge Mobile Home Park	Tributary Wolverine Creek	0.0033	08/31/2009
C-MC42-NO01	Lake Frances-Redfield	NA	No Discharge	Unknown
I-MC11-PO02	Ash Grove Quarry-Fort Scott East	Unknown	Stormwater	Unknown
I-MC11-PO06	Ash Grove Quarry-Fort Scott South	Unknown	Stormwater	Unknown
I-MC11-PO09	Nelson Quarries-Fort Scott	Tributary Mill Creek	Stormwater	10/31/2009
I-MC11-PO10	Fort Scott Water Treatment Plant	NA	Inactive	12/31/2010
I-MC11-PO11	Nelson Quarries-Renard & Camerlink	Unknown	Stormwater	Unknown
I-MC11-PO12	Nelson Quarries-Fort Scott South	Unknown	Stormwater	Unknown
I-MC11-PR01	O’ Brien Ready Mix-Fort Scott	Unknown	No Discharge	Unknown
I-MC27-PO04	Mulberry Limestone Quarry-Mulberry	Unknown	Stormwater	Unknown
I-MC46-PO01	Ash Grove Quarry-Uniontown #84	Unknown	Stormwater	Unknown

[6] According to Kansas Statutes Annotated 65-171d(c)(3), in Kansas one animal unit equals approximately 0.7 mature dairy cattle, 10 swine weighing 55 pounds or less, and 2.5 swine weighing greater than 55 pounds.

Facility ID	Facility Name	Receiving Stream	Design Flow (MGD)	Permit Expiration Date
I-MC52-PO01	Midwest Minerals- #4 Farlington Quarry	Unknown	Stormwater	Unknown
I-MC52-PO02	Public Wholesale District #11-Bone Cr.	Bone Creek	0.023	12/31/2009
I-MC59-PO01	Mulberry Limestone Quarry-Englevale	Unknown	Stormwater	Unknown
I-MC61-PO03	Phoenix Coal Co.-Garland Mine	Tributary Buck Run Creek	Stormwater	01/31/2014
I-MC61-PO04	Phoenix Coal Co.-Garland Mine #2	Tributary Buck Run Creek	Stormwater	06/30/2011
M-MC03-OO01	City of Arcadia WWTP	Tributary Cox Creek	Unknown	09/30/2009
M-MC06-OO01	City of Bronson WWTP	Tributary Marmaton River	0.064	06/30/2009
M-MC11-OO02	City of Fort Scott WWTP	Marmaton River	3.0	03/31/2014
M-MC25-OO01	City of Moran WWTP	Tributary Marmaton River	0.098	06/30/2009
M-MC27-OO01	City of Mulberry WWTP	Tributary Cox Creek	0.083	03/31/2014
M-MC42-OO01	City of Redfield WWTP	Tributary Marmaton River	0.020	09/30/2009
M-MC46-OO01	City of Uniontown WWTP	Marmaton River	0.041	03/31/2014
M-MC52-OO01	Crawford County Sewer District #4	Tributary West Fork Drywood Creek	0.03	03/31/2014
M-MC66-NO01	City of Elsmore WWTP	NA	No Discharge	Unknown
P-MC11-OO01	Anodizing, Inc.	NA	Pretreatment	Unknown
P-MC11-OO02	Peerless Products, Inc.	NA	Pretreatment	Unknown

Note: WWTP = Wastewater treatment plant.
NA = Not applicable – facility does not discharge.

Table 6. Kansas livestock facilities in the Marmaton River watershed.

Active Livestock Permits		
Permit Number	**Type**	**Animal Units**[7]
A-MCBB-K001	Dogs	0
A-MCBB-M003	Dairy	340
A-NECR-B001	Beef	315
A-MCBB-S009	Swine	258
Active Livestock Certificates		
Certificate Number	**Type**	**Animal Units**
A-MCBB-BA01	Beef	300
A-MCBB-BA05	Beef	100
A-MCBB-BA06	Beef	100
A-MCBB-MA06	Dairy	70

3.2 Nonpoint Sources

Nonpoint sources include all other categories not classified as point sources. Potential nonpoint sources contributing to the low dissolved oxygen impairment in the Marmaton River watershed include runoff from agricultural areas, runoff from urban areas, onsite wastewater treatment systems, and various sources associated with riparian habitat conditions. Each of these sources is discussed further in the following sections.

3.2.1 Runoff from Agricultural Areas

The 2005 land use/land cover data indicates there are nearly 160,000 acres of cropland in the Marmaton River watershed, with roughly two-thirds of this area in Missouri (see Table 1) (MoRAP 2005 and KARS 2008). Lands used for agricultural purposes can be a source of nutrients and oxygen-consuming substances in the river. Accumulation of nitrogen and total phosphorus on cropland occurs primarily from decomposition of residual crop material and fertilization with chemical and manure fertilizers. Nutrients and organic materials from crop fields are transported to adjacent streams during precipitation events through the processes of subsurface flow, surface runoff and soil erosion. These processes can be compounded by tilling of farm fields and by applying fertilizers prior to precipitation events or at rates exceeding the assimilative capacity of the soil. As noted in Section 2.3, roughly 89 percent of the soils in the Marmaton River watershed in Missouri have low infiltration rates, and roughly 30 percent of the land area is considered highly or potentially highly erodible. In Kansas, greater than 99 percent of the watershed produces runoff under relatively low potential conditions.

Countywide data from the National Agricultural Statistics Service (USDA 2009) were combined with the land cover data for the Marmaton River watershed to estimate there are approximately

[7] As defined in Kansas statute KSA 65-171d(c)(3).

49,478 cattle in the Missouri portion of the watershed[8]. Livestock specialists in Barton and Vernon Counties have confirmed that the majority of the cattle being raised in this area are in cow/calf grazing operations[9]. These cattle are therefore most likely located on the approximately 159,911 acres of grassland/pastureland on the Missouri side of the Marmaton River watershed, and runoff from these areas can also be a potential source of nutrients and oxygen-consuming substances. For example, animals grazing in pasture areas deposit manure directly upon the land surface and, even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can become barren of plant cover, increasing the possibility of erosion and contaminated runoff during a storm event. When pasture land is not fenced off from the stream, cattle or other livestock may contribute nutrients directly to the stream while walking in or adjacent to the water body. The potential for cattle grazing to impact water quality takes on additional significance in light of the fact that grassland comprises nearly 47 percent of the Missouri portion of the Marmaton River watershed.

When considering the potential impacts of crop production and livestock grazing in the Marmaton River watershed, it is worth noting that pecans are a major crop in Vernon County. Vernon County is home to 30 percent of all pecan farms in the state, and roughly 71 percent of all acreage devoted to growing pecans. This is significant because pecan trees in Missouri require deep, well drained soils with adequate moisture, and are largely grown in the floodplains of major rivers (Reid 2000). Given the concentration of orchards in the vicinity, it is reasonable to assume that some are located in the wide alluvial valleys of the Marmaton River. In addition to requiring fertilization, pecan orchards can also be subject to livestock grazing, a management strategy designed to minimize ground cover. Both practices can be sources of nutrients to the Marmaton River, particularly during periods of flooding.

An additional potential source of nutrients from agricultural lands may come from the application of animal manure to cropland and livestock pastures. Under the right conditions, land application serves both as an inexpensive method for disposing of waste from large-scale animal feeding operations and as a readily available fertilizer to improve the growth of crops and forage. However, as noted above, too much manure applied at the wrong times can result in excess nutrients and organic matter reaching nearby streams. While poultry production in Missouri is concentrated in the southwest corner of the state, waste generated from these facilities is applied to crop and pasture land as far north as Vernon County (Darrick Steen, Missouri Department of Natural Resources, personal communication, August 21, 2009 and Mark Curtis, District Manager, USDA Natural Resources Conservation Service, personal communication, February 2, 2010). In addition, permitted swine and poultry operations within the watershed apply manure to 1,098 acres of their own land, and have spreading agreements to land apply to an additional 490 acres. These additional acres may or may not be in the watershed, and it is not known exactly how many acres in the watershed receive land applied animal waste. See Section 12.2 of this TMDL for further discussion of this topic.

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[8] According to the National Agricultural Statistic Service, there are an estimated 122,300 head of cattle in Vernon and Barton Counties (USDA 2007). According to the 2005 Missouri Resource Assessment Partnership, there are 617.7 square miles of grassland in Vernon and Barton Counties (MoRAP 2005). These two values result in a cattle density of approximately 198 cattle per square mile of grassland. This density was multiplied by the number of square miles of grassland in the Marmaton River watershed to estimate the number of cattle in the watershed.

[9] Al Decker, Livestock Specialist, University of Missouri Extension Service, Vernon County; personal communication, February 1, 2010, and Dona Goede, Livestock Specialist, University of Missouri Extension Service, Barton County; personal communication June 2, 2010.

Employing a similar analysis with agricultural and land use data from Kansas, it is estimated there are 63,493 cattle in the Kansas portion of the Marmaton River watershed, with a density of 104 cattle per square mile (KARS 2008 and USDA 2009). This density is variable and dependent upon the locations of the concentrated animal feeding operations in the watershed (there are no such cattle operations in the Missouri portion).

The National Agricultural Statistics Service also reports there were approximately 398,523 hogs and pigs, 1,303 sheep and lambs, and 5,362 poultry layers in Barton and Vernon Counties in Missouri in 2007. In addition, in 2007 there were at least 842 hogs and pigs, 621 sheep and lambs, and 2,185 poultry layers in the three counties in Kansas that include the Marmaton River watershed. No data are available to estimate the number of these other livestock that might be located in the Marmaton River watershed (USDA 2009).

3.2.2 Runoff from Urban Areas

Stormwater runoff from urban areas can also be a significant source of nutrients and oxygen consuming substances. In fact, phosphorus loads from residential areas can be comparable to or higher than loading rates from agricultural areas (Reckhow *et al.* 1980; Athayde *et al.* 1983). In addition, stormwater runoff from parking lots and buildings is warmer than runoff from grassy and woodland areas. This difference in surface runoff temperature can lead to higher instream water temperatures that lower the dissolved oxygen saturation capacity of the stream. Excessive discharge of suspended solids from urban areas can also lead to streambed siltation problems. Furthermore, leaking or illicitly connected sewers can also be a significant source of pollutant loads from urban areas.

Although only about 2.2 percent of the entire Marmaton River watershed is classified as urban – 2.8 percent in Missouri and 1.7 percent in Kansas – urban stormwater runoff could be considered a potentially significant source of the pollutants of concern based on the relative size and location of the two major urban areas within the watershed. Fort Scott accounts for 47 percent of the total population and 72 percent of the urban land area on the Kansas side of the watershed, and Nevada accounts for 47 percent of the total population and 71 percent of the urban land area on the Missouri side. Furthermore, the Marmaton River runs through Fort Scott just upstream of Missouri’s impaired segment, where it likely receives runoff and storm sewer discharges from the city. In Missouri, the city of Nevada is situated adjacent to the confluence of Little Drywood Creek and the Marmaton River, with tributaries acting as potential conveyances for stormwater and pollutants flowing from the city directly to each of these impaired water bodies.

3.2.3 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems that are properly designed and maintained should not serve as a source of contamination to surface waters. However, onsite wastewater treatment systems (e.g., septic systems) do fail for a variety of reasons. When these systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters. Failing septic systems are sources of nutrients and oxygen-consuming substances that can reach nearby streams through both surface runoff and subsurface flow.

The exact number of onsite wastewater treatment systems in the Marmaton River watershed is unknown. However, the estimated rural population of the entire watershed is approximately 12,235 persons with an estimated rural population in the Missouri portion of 7,038 persons[10] (U.S. Census Bureau 2000). Based on this population, and an average density of 2.5 persons per household, there may be approximately 4,894 systems in the entire watershed, with 2,815 of those in Missouri.

No precise information exists on the failure rate of onsite wastewater treatment systems within the Marmaton River watershed. The only available information comes from complaints that are received by the Barton and Vernon County Health Departments, which have regulatory authority over onsite wastewater systems. It is estimated that Vernon County receives about 30 complaints regarding failing onsite wastewater systems each year (Steve Durnell, Inspector with Vernon County Health Department, personal communication, Aug. 24, 2009). Inspectors for the Barton County Health Department indicate that they have been working this year to bring five failing systems, most of which are associated with commercial businesses, into compliance, and that the rate of failure is likely much higher than the number for which they receive complaints (Mary Pat Scott, Inspector with Barton County Health Department, personal communication, Nov. 6, 2009). Overall, EPA reports that the statewide failure rate of onsite wastewater systems in Missouri is 30 to 50 percent (EPA 2002).

3.2.4 Riparian Corridor Conditions

Riparian corridor[11] conditions can also have a strong influence on instream dissolved oxygen. Wooded riparian buffers are a vital functional component of stream ecosystems and are instrumental in the detention, removal, and assimilation of nutrients before they reach surface water. Therefore, a stream with a good riparian zone is generally better able to moderate the impacts of high nutrient loads than a stream with poor habitat. Wooded riparian corridors can also help by providing shading that reduces stream temperatures, and cooler stream temperatures can result in increased dissolved oxygen saturation capacity of the stream.

Riparian areas can also be sources of natural background material that could possibly contribute to the low dissolved oxygen problem. While riparian areas that are wooded and have a diversity of natural vegetation can help mitigate conditions that cause low dissolved oxygen, leaf fall from vegetation near the water's edge, aquatic plants, and drainage from organically rich areas like wetlands may, at certain times and under certain conditions, be natural sources of oxygen consuming organic materials to downstream ecosystems (Mitsch and Gosselink 1993). In addition, riparian areas may also be impacted by logging, livestock grazing and other agricultural activities. Although the department does not have data to indicate how pecan orchards are classified in the land use and land cover data, as noted in Section 3.2.1 pecan cultivation is common in the floodplains of this region, and may also be a source of nutrients to the Marmaton River.

As indicated in Table 7, a very large proportion of the riparian corridor adjacent to the Marmaton River in Missouri is classified as wetlands, and an even larger proportion of the riparian corridor in Kansas is classified as forest and woodland. This large discrepancy is likely due in part to the

[10] The total watershed population minus the population of all urban areas.
[11] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

fact that the land cover data for Kansas contains no wetlands classification, and that the wetlands classification in Missouri includes forested riparian areas and other forested wetlands. Equally plausible, there may very well be more wetlands in Missouri and more forests in the riparian zone in Kansas. Whatever the explanation, our data indicates that the majority of the riparian area of the Marmaton River in both states – 76.6 percent – is comprised of wetlands or forests or both. By contrast, cropland and grassland make up only 6.5 percent and 8.2 percent, respectively.

Table 7. Percentage of land cover within the Marmaton River riparian corridor, 30-meter (MoRAP 2005 and KARS 2008).

Land Use/Land Cover	Marmaton River		
	Missouri	Kansas	Missouri & Kansas
Urban	0.4	1.2	0.9
Cropland	8.8	5.3	6.5
Grassland	4.3	10.3	8.2
Forest & Woodland	1.6	82	54.1
Open Water	19.8	1.3	7.7
Barren	0	0	0
Herbaceous	0.3	ND	0.1
Wetland	65	ND	22.5

Note MoRAP = Missouri Resource Assessment Partnership
KARS = Kansas Applied Remote Sensing Program
ND = No Data. At the time of this TMDL, no data were available to estimate area of herbaceous and wetland land cover in Kansas.

4 Applicable Water Quality Standards and Numeric Water Quality Targets

The purpose of developing a TMDL is to identify the pollutant loading that a water body can receive and still achieve water quality standards. Water quality standards are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S Code Title 33, Chapter 26, Subchapter III (U.S. Code 2009)). Water quality standards consist of three components: designated beneficial uses, water quality criteria to protect those uses, and an antidegradation policy.

4.1 Designated Beneficial Uses

The designated beneficial uses of the Marmaton River, Water Body ID 1308, are:

- Irrigation
- Livestock and Wildlife Watering.
- Protection of Warm Water Aquatic Life.
- Protection of Human Health (Fish Consumption).
- Whole Body Contact Recreation – Category B.

The designated beneficial use that is impaired is Protection of Warm Water Aquatic Life. The designated uses and stream classifications for Missouri may be found in the Water Quality Standards at 10 CSR 20-7.031(1)(C),-(1)(F) and Table H (Missouri Secretary of State 2009).

4.2 Numeric Criteria

This section presents Missouri's numeric criterion for dissolved oxygen and also provides a brief description of why dissolved oxygen is important to water quality, how it is measured, and how it is related to other water quality parameters.

Dissolved oxygen is one of the most critical characteristics of our surface waters because fish, mussels, macroinvertebrates, and most other aquatic life utilize dissolved oxygen in the water to survive. The water quality criterion for dissolved oxygen for all Missouri streams, except cold water fisheries, is a daily minimum of 5 milligrams per liter (mg/L) (10 CSR 20-7.031 Table A; Missouri Secretary of State 2009).

Dissolved oxygen in streams is affected by several factors including stream flow, water temperature, the amount of decaying organic matter in the stream, turbulence at the air-water interface and the amount of photosynthesis occurring in plants within the stream. Organic matter can come from wastewater effluent as well as agricultural and urban runoff. The rate at which organic matter decays and consumes oxygen is measured as biochemical oxygen demand, or BOD.

Organic matter can also accumulate on the bottom of streams, where the rate at which it decays and consumes oxygen is measured as sediment oxygen demand, or SOD. Sediment oxygen demand is a combination of all of the oxygen-consuming processes that occur at or just below the sediment/water interface and can account for a large fraction of the oxygen consumption in a stream. Most of the sediment oxygen demand at the surface of the sediment is due to the biological decomposition of organic material and the bacterially facilitated nitrification of ammonia, while the sediment oxygen demand several centimeters into the sediment is often dominated by the chemical oxidation of species such as iron, manganese, and sulfide (Wang, 1980; Walker and Snodgrass, 1986). Sediment oxygen demand can also be affected by water depth, current velocity and temperature.

Nutrients can also contribute to low dissolved oxygen problems because nitrogen and phosphorus can accelerate algae growth in streams (EPA 2000a). Algae growth in streams is most frequently assessed based on the amount of chlorophyll *a* in the water. The algae consume dissolved oxygen during respiration and have the potential to remove large amounts of dissolved oxygen from the stream, particularly at night when dissolved oxygen is not produced through photosynthesis. The breakdown of dead, decaying algae also removes dissolved oxygen from water.

4.3 Antidegradation Policy

Missouri's Water Quality Standards include EPA's "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2) (Missouri Secretary of State 2010).

> Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after November 28, 1975, the date of EPA's first Water Quality Standards Regulation.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing or designated uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges, and exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

Waters in which a pollutant is at, near or exceeds the water quality criteria are considered in Tier 1 status for that pollutant. Therefore, the antidegradation goal for the Marmaton River is to restore the stream's dissolved oxygen level to the water quality standards.

5 TMDL Development

5.1 Data Collection

To fully understand the cause of the low dissolved oxygen problem, EPA Region 7 collected water quality data in the spring (April 21-24) and summer (August 25-28) of 2008 from the Marmaton River. Continuous water quality data were measured using data loggers deployed at three sites along the river and grab samples were taken on deployment and removal of the data loggers.

The locations of the Marmaton River sampling sites, along with modeled stream reaches and corresponding subbasins, are provided in Figure 4. A discussion pertaining to subbasin and stream reach characteristics can be found in Appendix C. The diurnal dissolved oxygen curves for the three sites for the summer of 2008 are presented in Figure 5, and the corresponding water quality data from the grab samples can be found in Table 8. The continuous water quality data, together with the water chemistry data obtained from the grab samples, were used in the development of a steady-state water quality model for the Marmaton River. The model was developed to characterize the diurnal fluctuation of dissolved oxygen and to serve as a basis for developing the TMDL for the impaired segment.

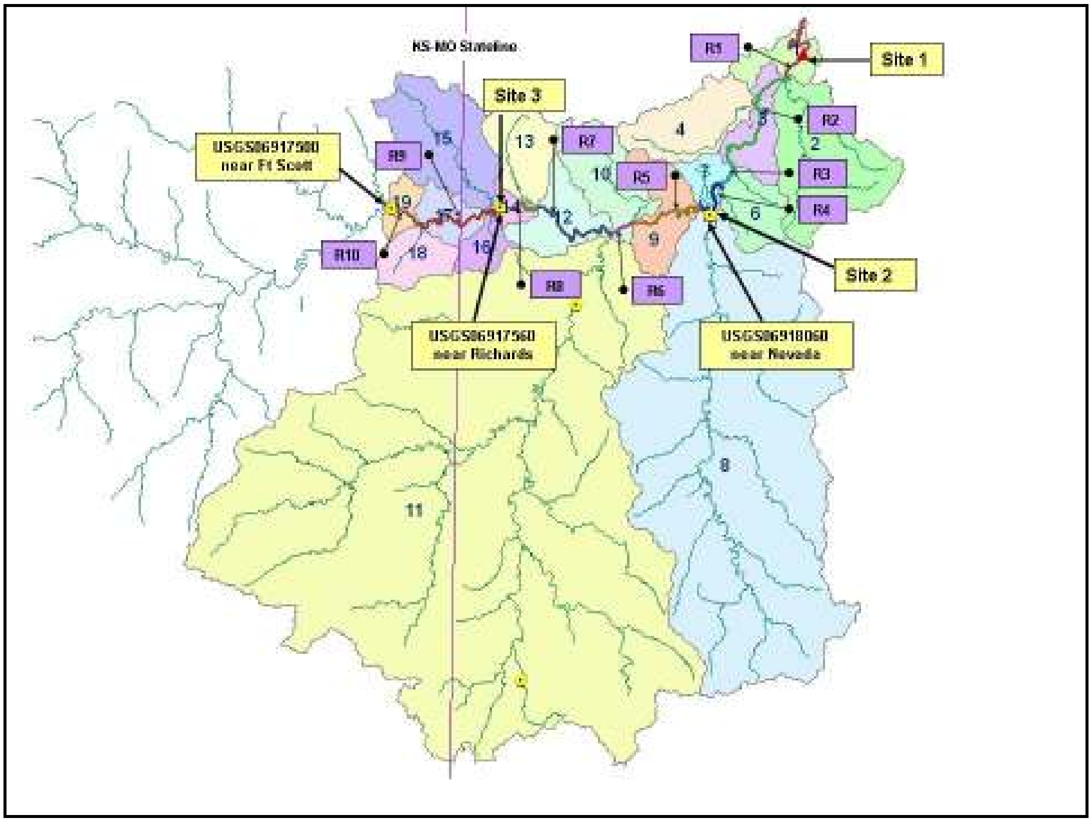

Figure 4. Location of Marmaton River sampling sites and schematic of model domain.

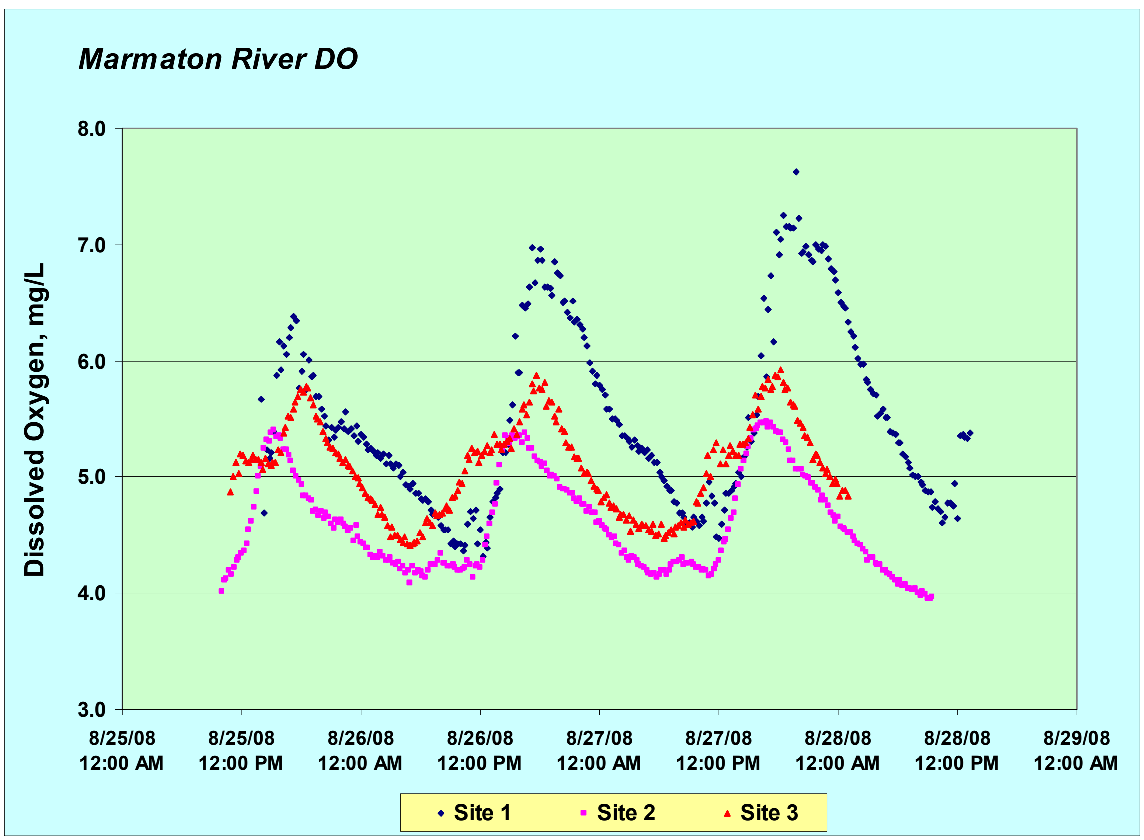

Figure 5. Continuous dissolved oxygen data for three sites on the Marmaton River.

Table 8. EPA water quality data for the Marmaton River.

Site	Date	Time	Temp	KSP	DO	pH	Alk	BOD5	CHLa	NH3-N	TKN
			deg C	µS/cm	mg/L		mg/L	mg/L	µg/L	µg/L	µg/L
Marmaton 1	4/21/2008	1529	15.4	389	7.5	7.7	102	2.0	4.4	100	783
Marmaton 1	4/24/2008	1447	18.2	351	7.8	7.2	74.6	4.0	9.5	100	3070
Marmaton 1	8/25/2008	1400	26.6	936	5.67	7.4	147	2.0		100	903
Marmaton 1	8/28/2008	1315	26.3	1065	5.38	7.5	150	2.3		100	591
Marmaton 2	4/21/2008	1440	14.9	457	7.5	7.8	116	2.0	3.8	100	813
Marmaton 2	4/24/2008	1045	17.7	346	6.2	7.9	94.5	7.0	10.5	100	2060
Marmaton 2	8/25/2008	1000	24.8	1122	4.01	6.9	155	2.0		100	1210
Marmaton 2	8/28/2008	0930	25.4	1139	3.97	7.4	164	2.0		125	713
Marmaton 3	4/21/2008	1144	14.8	329	8.1	8.0	140	2.2	4.1	100	846
Marmaton 3	4/24/2008	1133	17.6	214	6.9	8.1	97	6.2	11.6	100	2760
Marmaton 3	8/25/2008	1050	23.9	523	4.87	7.4	192	2.0		125	1200
Marmaton 3	8/28/2008	1030				7.4	195	2.0		100	666
Site	**Date**	**Time**	**NO23-N**	**TP**	**dOP-P**	**TSS**	**TOC**	**NVSS**	**VSS**	**Turb**	**SS**
			µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	ntu	ml/l/hr
Marmaton 1	4/21/2008	1529	424	230	38	100	7.2	46.7	53.3	344	1.0
Marmaton 1	4/24/2008	1447	389	2280	49	440	12.8	352.4	87.6	345	1.0
Marmaton 1	8/25/2008	1400	588	1390	15	32.8	6.6	21.3	11.5	73	1.0
Marmaton 1	8/28/2008	1315	580	376	25	37.8	4.7	28.8	9.0	114	1.0
Marmaton 2	4/21/2008	1440	411	408	38	72	7.8	42.7	29.3	116	1.0
Marmaton 2	4/24/2008	1045	493	2710	62	710	16.2	610.6	99.4	741	1.0
Marmaton 2	8/25/2008	1000	839	1170	91	38.4	6.3	31.3	7.1	99	1.0
Marmaton 2	8/28/2008	0930	656	1050	127	27.8	5.0	20.1	7.7	144	1.0
Marmaton 3	4/21/2008	1144	560	457	62	43	8.6	27.7	15.3	74	1.0
Marmaton 3	4/24/2008	1133	357	2260	66	810	17.4	529.7	280.3	771	1.0
Marmaton 3	8/25/2008	1050	142	3170	21	22.8	4.1	12.0	10.8	57	1.0
Marmaton 3	8/28/2008	1030	150	697	41	9.8	5.4	7.1	2.7	50	1.0

Note: SS = Settlable solids

5.2 Diurnal Dissolved Oxygen Analysis

The continuous dissolved oxygen data were analyzed using a single-station diurnal curve analysis model (Odum 1956 and Kosinski 1984). The single-station method allows the determination of the relative magnitudes of stream reaeration, total community respiration and net and gross primary production.

The Kansas Biological Survey, or KBS (Anderson and Huggins 2003), developed a spreadsheet model based on the single-station method. The KBS spreadsheet determines instream values for respiration, gross productivity, and net productivity and was used as the basis for the Little Osage River modeling study. Because the KBS spreadsheet model requires an independent estimate of stream reaeration, reaeration rates for the Marmaton River were estimated using the surface renewal method of O'Connor and Dobbins (1956). Considering the estimated depths and velocities of the river observed during the sampling events of summer 2008, the O'Connor and

Dobbins equation is an appropriate means of determining an estimate of stream reaeration, as indicated in Table 9 (Wilcock 1988).

Table 9. Suggested reaeration equations for flow depths and velocities (Wilcock 1982 as cited by Anderson and Huggins 2003).

Velocity, U (m/s)	Depth, z (m)			
	0.25 – 0.50	0.50 – 1.0	1.0 – 3.0	3.0 – 6.5
0.1 – 0.3	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins
0.3 – 0.5	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins
0.5 – 1.0	Negulescu-Rojanski	Isaacs-Gaudy	Chuchill-Elmore-Buckingham	Chuchill-Elmore-Buckingham
1.0 – 2.0	Negulescu-Rojanski	Isaacs-Gaudy	Chuchill-Elmore-Buckingham	Chuchill-Elmore-Buckingham

The summary of the single-station dissolved oxygen analysis for the Marmaton River is presented in Table 10. The table shows that the estimate of total community respiration exceeds the gross primary production for all the sites during the summer sampling period. Total community respiration exceeding gross primary production resulted in a negative net production. Results of the single-station dissolved oxygen diurnal curve analysis were used to guide the parameterization of the water quality model for Marmaton River.

Table 10. Estimates of gross productivity, net productivity and respiration for the Marmaton River, August 25 – 28.

Marmaton River	Reaeration $k_{2,20}$ 1/day	Net Production $gO^2/m^2/day$	Respiration $gO^2/m^2/day$	Gross Production $g\ O^2/m^2/day$
Site 1	3.73	-5.76	7.39	1.63
Site 2	3.74	-9.98	11.59	1.61
Site 3	3.74	-8.76	9.98	1.22

Note: $k_{2,20}$ 1/day = Reaeration constant at 20° Celsius per day.
$gO^2/m^2/day$ = grams of oxygen per square meter per day.

5.3 TMDL Modeling[12]

Dissolved oxygen in streams is determined by the factors of photosynthetic productivity, respiration (autotrophic and heterotrophic), reaeration and temperature. These factors are influenced by natural and anthropogenic conditions within a watershed. Generally, reaeration is based on the physical properties of the stream and on the capacity of water to hold dissolved oxygen. This capacity is mainly determined by water temperature, with colder water having a higher saturation concentration for dissolved oxygen. In a review of variables and their importance in dissolved oxygen modeling, Nijboer and Verdonschot (2004) categorized the impact of a number of variables on oxygen depletion. While temperature and stream flow may

[12] EPA Region 7 performed the modeling for this TMDL.

be significant factors in the dissolved oxygen conditions of a river, for this TMDL the effects of temperature and the physical aspects of the stream itself were discounted. Although the hydrologic regimes of historic prairie streams have been modified by changes in land cover, channelization and construction of surface water impoundments, manipulation of these parameters does not address a pollutant and so is not the goal of a TMDL. Pollutants that result in oxygen concentrations below saturation are:

- fine particle size of bottom sediment
- high nutrient levels (nitrogen and phosphorus)
- suspended particles of organic matter

Because these three variables vary to a large extent based on anthropogenic influences, they are appropriate targets for a TMDL written to address an impairment of low dissolved oxygen.

5.3.1 Load Duration Curves

5.3.1.1 Nutrients

To address nutrient levels of total nitrogen and total phosphorous, the EPA nutrient ecoregion reference concentrations were used. These targets are based on the 25th percentile of all total nitrogen and total phosphorus data gathered from the ecoregion, where data are not directly influenced by permitted dischargers (EPA 2000b). For the Central Irregular Plains (Level III 40) ecoregion where The Marmaton River is located, the reference concentration for total nitrogen[13] is 0.855 mg/L and the reference concentration for total phosphorus is 0.092 mg/L (EPA 2000b).

First, total nitrogen and total phosphorus measurements were collected from USGS sites in the vicinity of the impaired stream segment (Table B.3 in Appendix B). These data were adjusted such that the median of the measured data was equal to the EPA-recommended ecoregion reference concentration for each nutrient parameter. This was accomplished by subtracting from the measured data the difference between the reference concentration and the median from the measured data. Where this would result in a negative concentration, the data point in question was replaced with the minimum concentration seen in the measured data. This resulted in a modeled data set which retained much of the original variability found in the measured data. These modeled data were then regressed as instantaneous load versus flow. The resultant regression equation was used to develop the load duration curve.

To develop the TMDL expression of maximum daily loads, the background discharge at the stream outlet was modified from the traditional approach using synthetic flow estimation. Since the design flows from permitted facilities would overwhelm the natural background low flow, the sum of permitted facility design flows was added to the derived stream discharge at all percentiles of flow to take into account the increase in flow volume as well as pollutant load. See Appendix B for a complete discussion of the development of synthetic flow estimates and nutrient targets.

[13] Total nitrogen is the sum of total Kjeldahl nitrogen and nitrate plus nitrite as nitrogen.

5.3.1.2 Total Suspended Solids

Since fine particle sized sediment and suspended particles of organic matter are derived from similar loading conditions of terrestrial and stream bank erosion, this TMDL will have total suspended solids (sediment) as one of its allocations. To develop a load duration curve for total suspended solids, a method similar to that used for total nitrogen and total phosphorus was employed (see Appendix B). This target was derived based on a reference approach by targeting the 25th percentile base load concentration (5.75 mg/L) of total suspended solids measurements collected by the U.S. Geological Survey, or USGS, in the ecological drainage unit, or EDU, where the Marmaton River is located (see Table B.3 in Appendix B for a list of sites and data)[14].

As with nutrients, the TMDL expression of maximum daily loads for total suspended solids was developed using synthetic flow estimation, with the sum of permitted facility design flows added to the derived stream discharge at all percentiles of flow.

5.3.2 QUAL2K

An essential component of developing a TMDL is establishing a relationship between the source loadings and the resulting water quality. For this TMDL, the relationship between the source loadings of sediment oxygen demand and nutrients on dissolved oxygen is generated by the water quality model QUAL2K (Chapra, *et al*. 2007).

QUAL2K is supported by EPA and it and its predecessor (QUAL2E) have been used extensively for TMDL development and point source permitting issues across the country, especially for dissolved oxygen studies. QUAL2K is well accepted within the scientific community because of its proven ability to simulate the processes important to dissolved oxygen conditions within streams. The QUAL2K model is suitable for simulating the hydraulics and water quality conditions of a small river. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows, and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth, and dissolved oxygen dynamics.

A QUAL2K model was developed for the Marmaton River. The model was calibrated for the flow and water quality data measured in August 2008. The results of the model indicate that an average reduction in sediment oxygen demand of 60 percent is required to meet the dissolved oxygen criterion of 5 mg/L throughout the Missouri portion of the Marmaton River. Reductions in total suspended solids (organic matter), and nutrients are recommended in order to reduce sediment oxygen demand. A discussion of the TMDL allocations needed to achieve this 60 percent reduction is included in the following sections and a more detailed discussion of the QUAL2K model is included in Appendix C.

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[14] The Central Plains/Osage/South Grand River EDU.

6 Calculation of Load Capacity

Load capacity, or LC, is defined as the greatest amount of loading of a pollutant that a water body can receive without violating water quality standards. This load is then divided among the sum of the point source (wasteload allocation, or WLA) and nonpoint source (load allocation, or LA) contributions to the stream, with an allowance for an explicit margin of safety, or MOS. If the margin of safety is implicit, no numeric allowance is necessary. The load capacity of the stream can therefore be expressed in the following manner:

$$LC = \sum WLA + \sum LA + MOS$$

The wasteload allocation and load allocation are calculated by multiplying the appropriate stream flow in cubic feet per second, or cfs, by the appropriate pollutant concentration in mg/l. A conversion factor of 5.395 is used to convert the units (cfs and mg/L) to pounds per day (lbs/day).

(stream flow in cfs)(maximum allowable pollutant concentration in mg/L)(5.395)= pounds/day

Critical conditions must be considered when the load capacity is calculated. Dissolved oxygen levels that threaten the integrity of aquatic communities generally occur during low flow periods, so these periods are considered the critical conditions for the purpose of the dissolved oxygen model (QUAL2K).

7 Load Allocation (Nonpoint Source Load)

The load allocation includes all existing and future nonpoint sources and natural background contributions (40 CFR § 130.2(g)). The load allocations for the Marmaton River TMDL are for all nonpoint sources of total phosphorus, total nitrogen and total suspended solids. These can include loads from agricultural lands, including cultivated cropland and grassland utilized for livestock grazing, runoff from urban areas, animal feeding operations and failing or malfunctioning onsite wastewater treatment systems. TMDL load allocations for the entire Marmaton River watershed are provided in Tables 11, 13 and 15, and were calculated based on the total of all headwater and lateral inflow loads used in the QUAL2K model for the allocation scenario model run. The load allocations are intended to allow the dissolved oxygen target to be met at all locations within the stream under a variety of flow conditions.

Because the Missouri portion of the Marmaton River watershed accounts for 47.3 percent of the total watershed area, Marmaton River stream flow, TMDL values and nonpoint source load allocations were reduced proportionally from the allocations for the entire watershed. It should be noted that nonpoint source loads contributed by the Kansas portion of the watershed are not considered to cause or contribute to the impairment, and it is assumed that all applicable water quality standards are met at the state line. Consequently, although the entire watershed is considered, this TMDL does not set load allocations for nonpoint sources in Kansas. TMDL load allocations for the Missouri portion of the Marmaton River watershed can be found in Tables 12, 14 and 16.

8 Wasteload Allocation (Point Source Loads)

The wasteload allocation is the portion of the load capacity that is allocated to existing or future point sources of pollution. The sum of the design flows of all non-stormwater site-specific permitted dischargers (Table 3) in the Missouri portion of the Marmaton River watershed is 2.33 million gallons per day. Of this, a design flow sum of 2.05 million gallons per day is attributable to the Little Drywood Creek subbasin, which receives discharge from the Nevada Wastewater Treatment Plant. The sum of the design flows of all stormwater site-specific permitted dischargers in the Missouri portion of the Marmaton River watershed is 10.18 million gallons per day. The concentrated animal feeding operations in the Missouri portion of the watershed are assigned general permits and are currently not permitted to discharge except during storms exceeding the design storm event. These facilities are not expected to impact low dissolved oxygen during critical periods of low flow and, as a result, are not included in the sum of design flows and have not been assigned wasteload allocations.

To meet the total nitrogen, total phosphorus and total suspended solids critical condition targets outlined in this TMDL, the sum of the wasteload allocations was calculated by using nutrient ecoregion reference concentrations and 25th percentile total suspended solids concentrations and the sum of the design flows of all permitted facilities in the watershed. Because there are no permitted municipal separate storm sewer systems within the watershed, no wasteload allocations were necessary for this type of permit.

The load duration curves for the targeted pollutants for the Marmaton River are depicted in Figures 6 through 8. The "TMDL" curve represents the total load capacity of all point and nonpoint sources of pollutants, the "Sum of WLA" represents allocations for all site-specific point sources of pollutants with both static and stormwater-based design flows; and the "Non-Stormwater" curve represents allocations attributed to facilities with static design flows.

Marmaton River TMDL load capacities and wasteload allocations for nutrients and total suspended solids are outlined in Tables 11 through 16 for a range of flow conditions. Tables 11, 13 and 15 outline pollutant allocations for the entire Marmaton River watershed, including the portion of the watershed in Kansas. It is assumed that point source loads from the Kansas portion of the watershed do not cause or contribute to the impairment and that all applicable water quality standards are met at the state line. Consequently, although the entire watershed is considered, this TMDL does not set wasteload allocations for point sources in Kansas. Tables 12, 14 and 16 outline allocations for only the Missouri portion of the Marmaton River watershed. Because wasteload allocations are set only for Missouri, the wasteload allocations in Tables 12, 14 and 16 are the same as those for the entire watershed and represent the pollutant loads for which Missouri is responsible.

In addition to the nutrient and total suspended solids loads developed using load duration curves, the QUAL2K model was used to develop a wasteload allocation for carbonaceous biochemical oxygen demand, or $CBOD_5$. In order to meet the minimum water quality criterion of 5 mg/L for dissolved oxygen in the Marmaton River downstream of the confluence with Little Drywood

Creek, a $CBOD_5$ loading of 2.0 mg/L was assumed for Little Drywood Creek. To meet this loading at the confluence it was determined that the $CBOD_5$ wasteload allocation for the Nevada Wastewater Treatment Plant must be reduced to **7.75 mg/L**.

Note that the margin of safety for this TMDL is implicit and was not included in the allocations tables. Further discussion of the margin of safety can be found in Section 9.

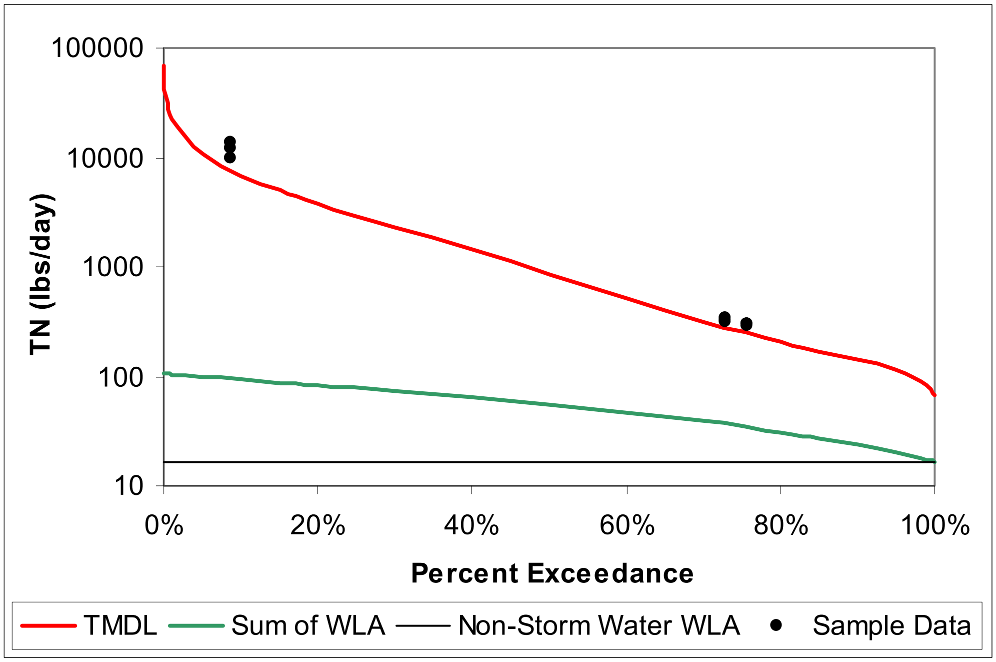

Figure 6. Marmaton River Load Duration Curve – Total Nitrogen.

Table 11. Marmaton River Total Nitrogen Allocations (lbs/day) – entire watershed

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	113.7	14.3	6.0	93.4
90%	30.3	139.7	14.3	9.7	115.7
70%	66.1	310.4	14.3	24.6	271.5
50%	176.4	862.8	14.3	41.0	807.5
30%	458.6	2332.3	14.3	58.6	2259.4
10%	1286.6	6826.8	14.3	77.7	6734.8
5%	2003.8	10826.9	14.3	83.4	10729.2

Table 12. Marmaton River Total Nitrogen Allocations (lbs/day) – Missouri only

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	64.5	14.3	6.0	44.2
90%	30.3	78.7	14.3	9.7	54.7
70%	66.1	167.3	14.3	24.6	128.4
50%	176.4	437.2	14.3	41.0	381.9
30%	458.6	1141.6	14.3	58.6	1068.7
10%	1286.6	3277.6	14.3	77.7	3185.6
5%	2003.8	5172.6	14.3	83.4	5074.9

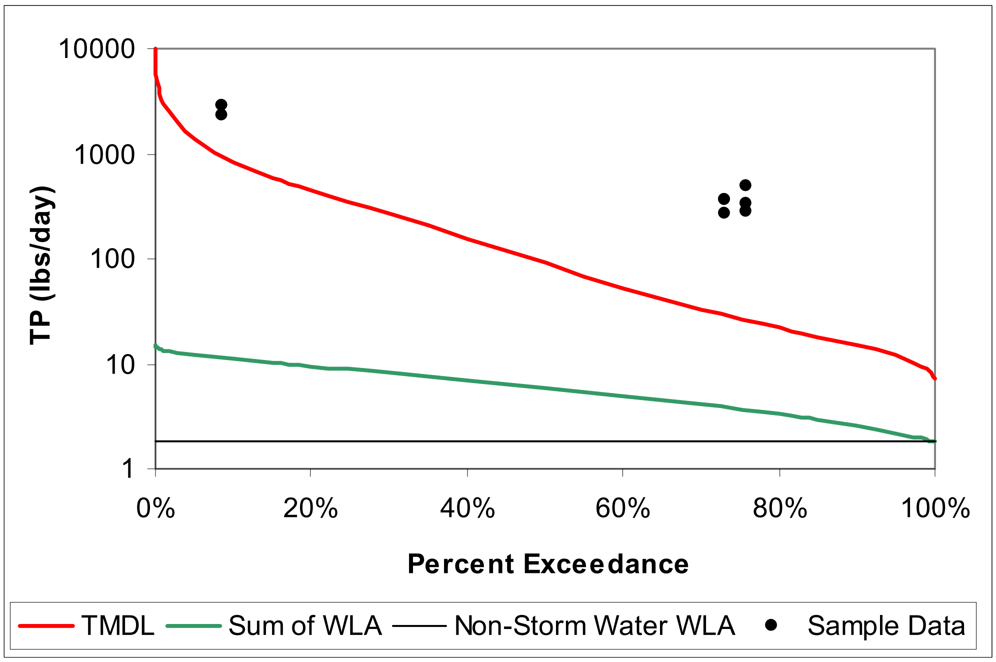

Figure 7. Marmaton River Load Duration Curve – Total Phosphorus.

Table 13. Marmaton River Total Phosphorus Allocations (lbs/day) – entire watershed

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	12.2	1.6	0.6	10.0
90%	30.3	15.0	1.6	1.0	12.4
70%	66.1	32.8	1.6	2.6	28.6
50%	176.4	91.0	1.6	4.3	85.1
30%	458.6	264.3	1.6	6.6	256.1
10%	1286.6	835.7	1.6	9.4	824.7
5%	2003.8	1370.1	1.6	10.5	1358.0

Table 14. Marmaton River Total Phosphorus Allocations (lbs/day) - Missouri only

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	6.9	1.6	0.6	4.7
90%	30.3	8.5	1.6	1.0	5.9
70%	66.1	17.7	1.6	2.6	13.5
50%	176.4	46.2	1.6	4.3	40.3
30%	458.6	129.3	1.6	6.6	121.1
10%	1286.6	401.1	1.6	9.4	390.1
5%	2003.8	654.4	1.6	10.5	642.3

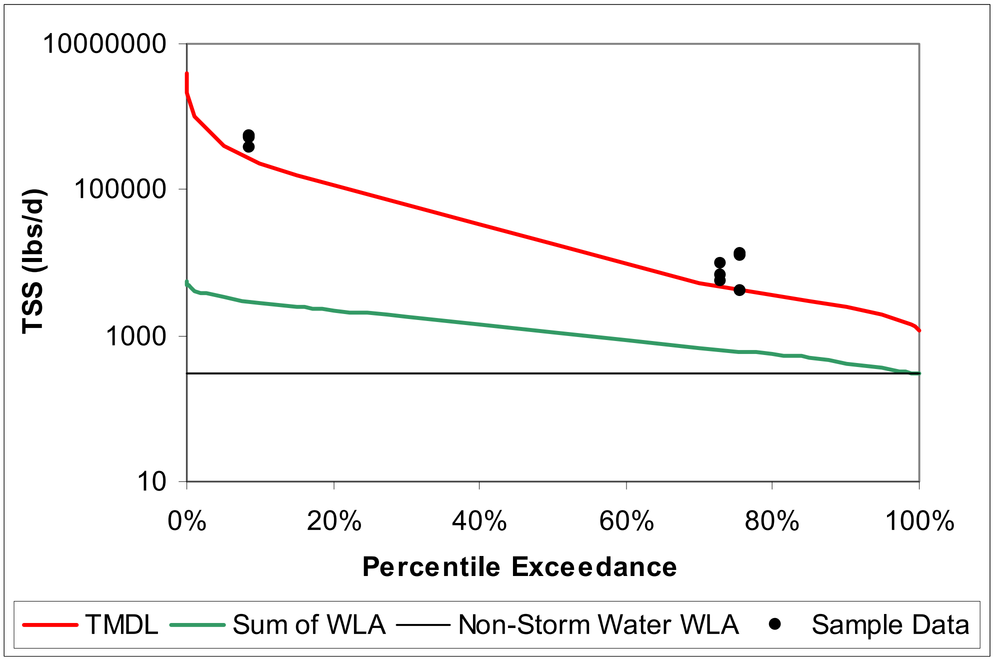

Figure 8. Marmaton River Load Duration Curve – Total Suspended Solids.

Table 15. Marmaton River Total Suspended Solids Allocations (lbs/day) – entire watershed

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	1994.6	250.9	105.7	1638.0
90%	30.3	2449.9	250.9	169.5	2029.5
70%	66.1	5346.4	250.9	424.9	4670.6
50%	176.4	18233.0	250.9	857.3	17124.8
30%	458.6	61856.5	250.9	1531.8	60073.8
10%	1286.6	231394.0	250.9	2596.0	228547.1
5%	2003.8	407738.4	250.9	3092.2	404395.3

Table 16. Marmaton River Total Suspended Solids Allocations (lbs/day) – Missouri only

Percentile flow exceedance	Flow (cfs)	TMDL (LC)	WLA Nevada WWTP	WLA (other permits)	LA
95%	24.6	1131.3	250.9	105.7	774.7
90%	30.3	1380.4	250.9	169.5	960.0
70%	66.1	2885.0	250.9	424.9	2209.2
50%	176.4	9208.2	250.9	857.3	8100.0
30%	458.6	30197.6	250.9	1531.8	28414.9
10%	1286.6	110949.6	250.9	2596.0	108102.7
5%	2003.8	194622.1	250.9	3092.2	191279.0

9 Margin of Safety

A margin of safety is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The margin of safety is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the margin of safety can be achieved through one of two approaches:

(1) Explicit - Reserve a portion of the load capacity as a separate term in the TMDL.
(2) Implicit - Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

The margin of safety for the Marmaton River TMDL is implicit and based on the conservative assumptions used in developing and applying the TMDL load duration curves. The use of ecoregion nutrient targets in lieu of national or state-wide nutrient targets helps ensure that implementation will result in minimally impacted stream systems.

Total nitrogen and total phosphorus targets are conservative because they are based on the 25th percentile of all total nitrogen and total phosphorus data gathered from reference streams in ecoregion 40, where data are not directly influenced by permitted dischargers. The 25^{th} percentile is considered a surrogate for establishing a reference population of minimally impacted waters (EPA 2000b). The targets are the median calculated from the four seasonal 25^{th} percentile values. As a result, both high concentrations seen during the periods of spring runoff and winter flow from snowmelt, and low concentrations seen during low flow conditions in both summer and fall, do not fully affect the annual reference targets.

In the case of sediment, the approach used was to target the 25^{th} percentile of all total suspended solids concentration data available in the Central Plains/Osage/South Grand EDU in which the Marmaton River is located (see Appendix B). The use of these refined and EDU-specific data ensures that all local landscape conditions are addressed in this TMDL.

10 Seasonal Variation

Federal regulations at 40 CFR §130.7(c)(1) require that TMDLs take into consideration seasonal variation in applicable standards. The Marmaton River TMDL addresses seasonal variation in two ways. One is by identifying a loading capacity that is protective of the critical low flow period sampled in August 2008. QUAL2K TMDL development for low dissolved oxygen during critical low-flow conditions are expected to be protective year round.

The second way in which the TMDL takes seasonal variation into account is through the use of load duration curves. Load duration curves represent the allowable pollutant load under different flow conditions and across all seasons. The results obtained using the load duration curve method are more robust and reliable over all flows and seasons when compared with those obtained under critical low-flow conditions.

11 Monitoring Plan for TMDLs Developed under Phased Approach

Post-TMDL monitoring will be scheduled to be conducted by the department approximately three years after the TMDL is approved, or in a reasonable period of time following any TMDL-based compliance schedule outlined in the permit and the application of any new effluent limits.

Additionally, the department will routinely examine physical habitat, water quality, invertebrate community, and fish community data collected by other state and federal agencies in order to assess the effectiveness of TMDL implementation. One example of such data is that generated by the Resource Assessment and Monitoring Program administered by the Missouri Department of Conservation. This program randomly samples streams across Missouri on a five to six year rotating schedule.

12 Implementation Plans

Since low dissolved oxygen is an issue in the Marmaton River both upstream and downstream of the confluence with Little Drywood Creek, addressing the sources of impairment in the Marmaton River will require developing nonpoint source, as well as point source, controls in the watershed. However, due to issues regarding low dissolved oxygen as a natural background condition in prairie streams, the department may seek to develop revised dissolved oxygen criteria for the Marmaton River and Little Drywood Creek during the next Triennial Review of the Water Quality Standards. The department acknowledges that, should revised criteria be developed, a revised Marmaton River TMDL may be necessary. It also acknowledges that the revised criteria may result in no difference for Marmaton River and that new loading calculations may not differ or offer relief from what is currently contained in this TMDL.

12.1 Point Sources

This TMDL will be implemented partially through permit action. The Missouri State Operating Permit for the city of Nevada's wastewater treatment plant expired Aug. 5, 2009, with renewal pending the completion of ongoing plant upgrades to add four clarifiers, two aeration basins, two aerobic digesters and ultraviolet disinfection. Pending effluent limits in the draft permit are 28 mg/L daily maximum and 20 mg/L monthly average for both biochemical oxygen demand and total suspended solids. Wasteload allocations for carbonaceous biochemical oxygen demand and total suspended solids developed in support of the TMDL will not immediately apply to revised effluent limits, but may apply subsequent to the first permit renewal following completion of facility upgrades. These effluent limits would be designed to be protective of the Marmaton River at the confluence with Little Drywood Creek.

The permit currently requires the facility to meet a removal efficiency of 85 percent or more for biochemical oxygen demand and total suspended solids, and the new permit will include an influent monitoring requirement for these two parameters. Although nutrient wasteload allocations will not be implemented at this time, the new permit will require effluent monitoring of total nitrogen and total phosphorus. The new permit will also require instream monitoring both upstream and downstream of the wastewater treatment plant in order to provide additional data with which to assess the impact of the revised permit limits on water quality. Instream data to be collected includes dissolved oxygen, temperature, ammonia, pH and chlorophyll *a*.

Wasteload allocations developed for this TMDL may be used to derive new limits for carbonaceous biochemical oxygen demand and total suspended solids that are protective of the dissolved oxygen criterion and aquatic life use in the Marmaton River. However, it is the intention of the department that prior to implementation of these wasteload allocations, either the department or the city will determine whether the dissolved oxygen criterion of 5 mg/L found in 10 CSR 20-7.031, Table A is appropriate or if site-specific dissolved oxygen criteria for the Marmaton River and Little Drywood Creek are required. This will likely coincide with the department's next Triennial Review of the Water Quality Standards, scheduled for 2012, when new dissolved oxygen criteria may be promulgated. Revised dissolved oxygen criteria may better reflect natural stream reaeration conditions to assure that treatment plant effluent limits are based on meeting dissolved oxygen criteria that are naturally attainable. Further, it is recommended that additional sampling, including biological sampling, be conducted in the affected segment of the Marmaton River prior to implementation of the wasteload allocations in order to assess the water body's attainment of designated beneficial uses. These sampling events should occur prior to the end of the calendar year 2012 and continue as necessary.

If it is determined at that time that the current water quality criterion for dissolved oxygen is appropriate, the wasteload allocations from the TMDL will be implemented using a phased, adaptive management approach. The Nevada Wastewater Treatment Plant permit may incorporate TMDL-based CBOD and TSS limits under a negotiated schedule of compliance to be issued in a subsequent permit renewal. Effluent monitoring for nutrient species and instream monitoring upstream and downstream of the wastewater treatment plant will continue to be conducted in order to assess the effectiveness of the revised permit limits. Should post-TMDL monitoring indicate initial reductions to CBOD and TSS limits result in attainment of numeric

and narrative water quality standards, TMDL-based total nitrogen and total phosphorus limits may not be required.

If the current water quality criterion for dissolved oxygen is determined not to be appropriate, and a new dissolved oxygen criterion is promulgated, then new wasteload allocations for carbonaceous biochemical oxygen demand and total suspended solids will be calculated and implemented. Along with implementation of any new wasteload allocations, effluent nutrient monitoring and instream monitoring for dissolved oxygen, temperature, pH, ammonia and chlorophyll *a* will continue to be required on the Nevada Wastewater Treatment Plant operating permit both upstream and downstream of the facility.

If post-TMDL monitoring indicates that point source reductions are not achieving the desired improvements in water quality, the department will reevaluate the TMDL for further appropriate actions. These actions may include additional permit conditions on the Nevada Wastewater Treatment Plant such as effluent limits for total nitrogen and total phosphorus, revised permit conditions on other permitted facilities, and further control of nonpoint sources through a nonpoint source management plan. If, at any point in this process, water quality and biological sampling determines that designated beneficial uses are being attained, either the city or the department may seek to have the Marmaton River removed from the 303(d) List of impaired waters.

As noted in the point source assessment in Section 3.1, the sum of all remaining non-stormwater permitted design flows is very small in comparison to the Nevada facility. As a result, these remaining permits will not be revised at this time to facilitate TMDL implementation. However, all permitted facilities within the Missouri portion of the impaired watershed will be inspected prior to next permit renewal to determine if best management practices or permit conditions are needed to ensure the facilities are not contributing nutrients or oxygen demanding pollutants to the Marmaton River. The inspections will include an assessment of the condition of the facilities and whether upgrades or additional measures are necessary.

While there are a number of permitted point sources on the Kansas side of the Marmaton River watershed, including the Fort Scott Wastewater Treatment Plant which is identified as a source of low dissolved oxygen impairment in Kansas, the state of Missouri has no authority to regulate these facilities. However, the department will notify the Kansas Department of Health and Environment upon completion of this TMDL, and remains committed to working with the state of Kansas to ensure that the Marmaton River continues to meet water quality criteria at the state line.

12.2 Nonpoint Sources

Although pollutant reduction through the establishment of wasteload allocations for the Nevada Wastewater Treatment Plant is an important component of this TMDL, load allocations account for a significant, and sometimes dominant, portion of the total load capacity. In some cases, this is true even at low flows. The implementation of this TMDL, therefore, must also be directed at pollutant reduction through control of nonpoint sources. This section will outline activities and

practices currently being used to address potential nonpoint sources of pollutants and will suggest additional measures that could be implemented to control future nonpoint sources.

In November 2005, the Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Committee was formed through the efforts of the Osage Valley Resource Conservation and Development Council. The aim of this committee was to facilitate a cooperative effort between residents within the Marais des Cygnes, Little Osage and Marmaton River watersheds to develop a comprehensive watershed management plan. The Marmaton River originates in Kansas and flows east into Missouri. The Missouri portion of the system accounts for about one-third of the river length and just under half of the total watershed area. The Marmaton River is joined by the tributary of Little Drywood Creek just west of the city of Nevada, and then flows for another 16 miles to its confluence with the Little Osage River. The watershed committee is composed of county commissioners and Soil and Water Conservation District boards in Barton, Bates, Cass and Vernon Counties, plus interested watershed residents. Natural resource agencies and watershed residents from Kansas and Missouri were invited to provide ideas and technical expertise. Four public meetings were held in February and March, 2005 and July, 2006 to obtain public input during plan development. Through this process, the following 10 issues and concerns were identified and prioritized:

- Erosion and soil loss.
- Solid waste management.
- Water quality and quantity.
- Public information.
- Quarries and other mines.
- Farmland conversion to residential land use.
- Habitat loss - aquatic and upland.
- Agricultural systems-concentrated animal feeding operation or animal feeding; Grazing and cropping systems.
- Private and Public Interaction.
- Residential and Urban.

The Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Management Action Plan was signed in August 2006 by Bates and Vernon County Commissioners, Bates and Vernon County Soil and Water Conservation Districts and the Osage Valley Resource Conservation and Development Council.

Currently, there are no Section 319 Nonpoint Source projects[15] under way in Missouri to implement that section of the watershed management plan relating to the Marmaton River. However, in recent years there have been a number of nonpoint source best management practices, or BMPs, funded through cost-share and other programs and implemented in both Missouri and Kansas. BMPs are recommended methods, structures, and practices designed to prevent or reduce water pollution. The concept of BMPs is one of a voluntary and site-specific

[15] These are projects intended to address nonpoint source pollution and are funded with grants administered by EPA Region 7 through the department's Section 319 Nonpoint Source Implementation Program. Section 319 refers to Section 319(h) of the federal Clean Water Act.

approach to water quality problems. Examples of practices recently put into place in the Marmaton River watershed include establishment of permanent vegetative cover, construction of terraces and grass-lined waterways to reduce soil erosion, establishment of field borders, nutrient management, fencing to keep livestock away from streams, and inclusion of land in both the Conservation Reserve and Wetland Reserve Programs.

To further reduce the loading and impact of nutrients and total suspended solids on the Marmaton River, additional efforts could be made to expand and better target the acres where BMPs are utilized. Such efforts include encouraging more farmers to adopt agricultural BMPs, encouraging farmers utilizing BMPs to expand and target these practices where they are most effective, and working to assist farmers in securing funding to implement BMPs on their land. Along with expanding the BMPs noted above, other agricultural practices that could be implemented include improved irrigation and water management, establishment of riparian buffers and filter strips, implementation of enhanced cropping techniques (such as no-till agriculture), and additional enhanced grazing practices that prevent or mitigate livestock-caused damage to streams and riparian areas.

Further efforts may also be warranted to address the management of animal waste from feeding operations both inside and outside of the watershed – in particular the application of waste as fertilizer on crop and pasture lands. Animal waste entering streams from surface runoff can contribute both nutrients and organic sediment that contribute to low dissolved oxygen. Although the Missouri Concentrated Animal Feeding Operation Nutrient Management Technical Standard adopted in March 2009 requires the development and implementation of field-specific Nutrient Management Plans, this regulation is specific only to on-site application of waste from Class I concentrated animal feeding operations with Missouri State Operating Permits. Waste originating from non-permitted feeding operations, or applied off-site from the feeding operation of origin, is not subject to this rule. Department guidelines outlining concentrated animal feeding operation BMPs specifically address land application of animal waste. Increased efforts to distribute these guidelines and encourage adoption of BMPs among both permitted and non-permitted facility operators represents an additional means to address loading of nutrients and organic sediment to the Marmaton River.

In addition to land use practices that may directly impact pollutant loading in the Marmaton River, another factor potentially contributing to the low dissolved oxygen impairment is low stream flow. While low stream flow itself is not a pollutant and flow is not a target of this TMDL, conditions in the watershed that affect flow, such as regulation of water quantity through surface water impoundment, are issues that may warrant attention during TMDL implementation. As noted in Section 2.4, there are a number of impoundments in both Missouri and Kansas affecting a significant portion of the watershed, as well as a number of additional proposed impoundments. Addressing this issue will require a more thorough understanding of the timing and quantity of flow required in order to sustain water quality and downstream uses in the Marmaton River. It will also require coordination and cooperation among stakeholders and regulatory agencies in both states involved in water resource planning and interstate water resource issues.

In an effort to most effectively implement land use BMPs, the department may work with the Natural Resources Conservation Service, or NRCS, and the local Soil and Water Conservation District to further encourage area farmers to implement and target these practices on their land. An additional approach may also be to work directly with the Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Committee and the Osage Valley Resource Conservation and Development Council to assist in securing funding, through Section 319 Nonpoint Source grants and other sources, to implement pollution control strategies outlined in the current Watershed Management Action Plan. The Watershed Committee may also be an effective medium for securing and utilizing resources – in the form of both funding and volunteers – to implement water quality monitoring in order to track the progress of TMDL implementation.

13 Reasonable Assurances

The department has the authority to issue and enforce Missouri State Operating Permits. For TMDLs that address point sources of pollutants, any effluent limits determined from TMDL wasteload allocations which may be incorporated into a state permit, along with effluent monitoring reported to the department, should provide a reasonable assurance that instream water quality standards will be met. In the case of the Marmaton River, however, permitted point sources are only part of the contribution to the impairment and, hence, regulatory effluent limits are only one part of the solution. Nonpoint sources of pollutants in the watershed must also be addressed.

Since "reasonable assurance" in reference to TMDLs is generally intended to address only point sources, any assurances that nonpoint source contributors of low dissolved oxygen will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources can be found in Section 12, "Implementation Plans", of this TMDL.

14 Public Participation

Much public effort went into writing the Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Management Plan. As mentioned in Section 12.2, this effort included four public meetings in 2005 and 2006 where ten major issues and concerns were identified and prioritized.

This water quality-limited segment of the Marmaton River is included on Missouri's 2008 303(d) List of impaired waters. EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). The initial public notice period for the draft Marmaton River and Little Drywood Creek TMDL was from February 4, 2010 to April 2, 2010. Eight comments were received during this comment period which resulted in substantial changes to the TMDL. Before finalizing the revised Marmaton River TMDL the public was notified of an additional 45 day comment period running from July 8, 2010 to August 22, 2010. Three comments were received during this comment period which resulted in minor revisions to the TMDL. Public notices to comment on the draft Marmaton River TMDL were distributed via mail and e-mail to major stakeholders in the watershed or other potentially impacted parties. Groups that received the public notice announcement included the Missouri Clean Water Commission, the department's

Water Quality Coordinating Committee, the Missouri Department of Conservation's Policy Coordinating Unit, Stream Team volunteers in the area, the Barton County and Vernon County Soil and Water Conservation Districts, the Barton County and Vernon County Commissions, the Osage Valley Resource Conservation and Development Council, and the state legislators representing Barton and Vernon Counties. In addition, since the Marmaton River originates in Kansas and flows into Missouri, a public notice announcement was also sent to the Kansas Department of Health and Environment, Bureau of Water. Finally, the public notice, the TMDL Information Sheet, and this document are posted on the department Web site, making them available to anyone with Internet access. All comments received, and the department's responses to those comments, have been placed in the Marmaton River administrative record.

15 Administrative Record and Supporting Documentation

An administrative record on the Marmaton River TMDL has been assembled and is being kept on file with the department. It includes the following:

- Marais des Cygnes Basin Total Maximum Daily Load for the Marmaton River, dissolved oxygen, Kansas Department of Health and Environment
- Marais des Cygnes Basin Total Maximum Daily Load for the Marmaton River, nutrients and oxygen demand impact on aquatic life, Kansas Department of Health and Environment
- Watershed Modeling Assessment of Marmaton River, Kansas Department of Health and Environment
- The Marias des Cygnes, Marmaton, and Little Osage Rivers Watershed Management Plan, 2006
- Watershed Restoration and Protection Strategy for the Marais des Cygnes Basin, Lake Region Resource Conservation and Development Council, 2003
- Effects of Impoundments and Land Cover Changes on Stream flows and Selected Fish Habitat in the Upper Osage River Basin, Missouri and Kansas, U.S. Geological Survey, 2007
- QUAL2K input and output files
- Load duration curve modeling data files
- Marmaton River TMDL Information Sheet
- Public notice announcement
- Public comments and comment responses

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Appendix A
Water Quality Data
Appendix A.1 – Marmaton River Historic Data
Collected by Army Corps of Engineers and Kansas Department of Health and Environment, 2000 - 2009

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB	TDS	BOD
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L
Below Ft. Scott, KS	2000	1	6	4	10.7	7.8	829		1.87	1.2		0.19	20	6.6	456.072	4.17
Below Ft. Scott, KS	2000	2	2	2	14.5	8.1	809		2.47	1.39		0.25	19	3.8	512.249	10.41
Below Ft. Scott, KS	2000	3	9	13	9.1	8.1	453		0.17	0.43		0.13	44	19	256.141	5.7
Below Ft. Scott, KS	2000	4	5	12	9.5	8	441		0.07	0.13		0.09	32	12.1	238.759	2.91
Below Ft. Scott, KS	2000	5	4	20	5.9	7.8	542		0.45	0.34		0.12	57	20	291.533	1.8
Below Ft. Scott, KS	2000	6	7	22	5	7.8	538		0.0099	0.65		0.22	71	31	315.589	7.11
Below Ft. Scott, KS	2000	7	6	29	5.7	7.9	382		0.0099	0.7		0.14	48	18	211.259	3.21
Below Ft. Scott, KS	2000	8	9	29	3.9	7.5	444		0.02	0.12		0.14	40	18	232.248	3.33
Below Ft. Scott, KS	2000	9	7	25	2.2	7.5	677		0.086	0.17		0.11	20	12	386.3	3.24
Below Ft. Scott, KS	2000	10	4	21	3.3	7.6	418		0.03	0.68		0.12	37	17	234.424	4.02
Below Ft. Scott, KS	2000	11	2	18	6.5	7.5	595		0.0099	0.86		0.163	33	14	340.928	5.01
Below Ft. Scott, KS	2000	11	29	5	9.7	7.6	512		0.67	0.87		0.147	25	6.5	285.94	6.66
Below Ft. Scott, KS	2001	1	4	0	6.4	7.5	1080		11.15	0.6		0.718	14	10	593.597	10.95
Below Ft. Scott, KS	2001	3	7	5	11.6	7.8	454		0.25	1.85		0.09	27	12	263.763	1.56
Below Ft. Scott, KS	2001	5	2	21	6.1	7.6	493.6		0.109	0.8		0.121	44	16	287.345	5.4
Below Ft. Scott, KS	2001	7	11	28	4.3	7.6	406.9		0.0099	0.08		0.208	64	28	233.74	2.34
Below Ft. Scott, KS	2001	9	6	25	4	7.5	428.2		0.033	0.09		0.179	50	24	243.055	3.6
Below Ft. Scott, KS	2001	10	31	13	6.8	7.5	614.4		0.0099	1.11		0.194	36		16	
Below Ft. Scott, KS	2002	2	6	4	12	7.7	320.2	1.576	0.276	1.02	2.6	0.186	31	29	185.966	
Below Ft. Scott, KS	2002	4	3	10	7.9	7.9	529.2	1.823	0.344	0.39	2.21	0.185	54	7.4	305.532	
Below Ft. Scott, KS	2002	6	5	24	6.3	7.5	446.2	1.074	0.269	0.35	1.42	0.153	56	20	261.433	
At Old Highway 71	2002	7	29	29	7.9	7.6	863	0.27	0.00499	0.15	0.42	0.14	52	45		
Below Ft. Scott, KS	2002	8	7	27	3.7	7.2	571.9	1.429	0.0499	0.07	1.5	0.187	47	23	333.224	
Below Ft. Scott, KS	2002	10	9	16	2.8	7	470.7	1.215	0.292	0.63	1.84	0.146	32	14	270.087	
Below Ft. Scott, KS	2003	1	8	4	8.8	7.5	1040	5.184	3.456	0.93	7.11	0.311	26	10.5	605.703	
Below Ft. Scott, KS	2003	3	5	3	11.1	7.8	501.9	1.385	0.707	1.59	2.98	0.131	14	2	305.804	
Below Ft. Scott, KS	2003	5	7	18	7	7.4	353.9	1.242	0.0499	0.34	1.58	0.172	113	17	210.97	
Below Ft. Scott, KS	2003	7	9	28	4.1	7.2	553.5	1.122	0.0499	0.07	1.19	0.129	27	24.8	337.63	
Below Ft. Scott, KS	2003	9	10	22	5.1	7.9	358.2	1.155	0.0499	1.19	2.34	0.236	67	61.5	214.853	

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB	TDS	BOD
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L
Below Ft. Scott, KS	2003	11	5	12	2.7	7.1	639.8	2.063	0.39	0.85	2.91	0.183	18	14.7	373.738	
Below Ft. Scott, KS	2004	4	7	14	9.1	7.3	433	0.54	0.0499	0.37	0.91	0.09	29	18.2	263	
Below Ft. Scott, KS	2004	6	9	24	4.5	7.5	388	0.55	0.0499	0.43	0.98	0.16	51	44.6	241	
Below Ft. Scott, KS	2004	8	4	26	6	7.4	508	0.48	0.0499	0.47	0.95	0.17	38	27.1	313	
Below Ft. Scott, KS	2004	10	6	15	6.7	7.5	484	0.64	0.0499	0.13	0.77	0.2	28	36.3	285	
Below Ft. Scott, KS	2004	12	8	8	10.5	7.3	280	0.98	0.0499	0.0499	1.03	0.18	41	46.8	175	
Below Ft. Scott, KS	2005	3	9	8	10.8	7.7	485	0.36	0.0499	0.0499	0.41	0.05	14	13.4	278	
Below Ft. Scott, KS	2005	5	4	13	8.3	7.8	539	0.47	0.0499	0.38	0.85	0.09	22	14	310	
Below Ft. Scott, KS	2005	7	13	25	4.5	7.3	500	0.51	0.0499	0.42	0.93	0.14	38	25.4	308	
Below Ft. Scott, KS	2005	9	14	23	4.6	7.2	569	0.81	0.0499	0.53	1.34	0.09	37	27.1	331	
Below Ft. Scott, KS	2005	11	9	16	2.8	7	621	0.43	0.0499	1.61	2.04	0.11	4.99	2.1	375	
Below Ft. Scott, KS	2006	2	1	8	9	7.3	622	0.62	0.0499	0.75	1.37	0.04	10	6.6	348	
Below Ft. Scott, KS	2006	4	5	15	7.1	7.4	500	1.04	0.0499	0.64	1.68	0.2	46	37.4	283	
Below Ft. Scott, KS	2006	6	7	25	5.4	7.5	477	0.57	0.0499	0.18	0.75	0.11	35	30.1	282	
Below Ft. Scott, KS	2006	8	9	28	4	7.3	705	0.94	0.12	0.95	1.89	0.1	22	20.1	405	
Below Ft. Scott, KS	2006	10	4	23	4.6	7.2	581	0.84	0.499	1.81	2.65	0.05	15	6.5	327	
Below Ft. Scott, KS	2006	11	29	13	6.2	7	550	0.69	0.499	1.7	2.39	0.06	13	9.5	313	
Below Ft. Scott, KS	2007	1	10	4	11.2	7.5	448	0.83	0.499	0.86	1.69	0.1	4.99	6.4	258	
Below Ft. Scott, KS	2007	3	7	9	10.7	7.6	434	1.03	0.499	1.04	2.07	0.08	22	23.3	240	
Below Ft. Scott, KS	2007	5	9	20	7.1	7.3	266	0.8	0.499	0.34	1.14	0.18	49	49.5	157	
At Old Highway 71	2007	5	23					0.59	0.0386	0.59	1.18	0.123	50.8	53.4		
At Old Highway 71	2007	6	13					1.1	0.0786	0.27	1.37	0.147	86	30.2		
At Old Highway 71	2007	7	11					0.54	0.0545	0.3	0.84	0.141	68	28.1		
Below Ft. Scott, KS	2007	7	11	26	6.6	7.4	319	0.7	0.0499	0.22499	0.92499	0.11	38	30	185	
At Old Highway 71	2007	8	29					0.49	0.0089	0.65	1.14	0.121	28.8			
Below Ft. Scott, KS	2007	9	12	20	6.7	7.3	395	0.6	0.0499	0.07489	0.67489	0.16	51	44	223	
Below Ft. Scott, KS	2007	10	31	14	7.3	7.2	370	0.7	0.0499	0.43499	1.13499	0.08	24	18	216	
Below Ft. Scott, KS	2008	4	9	11	10.4	8	377	0.8	0.0499	0.25499	1.05499	0.1	47	44	218	
Below Ft. Scott, KS	2008	6	4	23	7.3	7.2	326	0.9	0.0499	0.37499	1.27499	0.15	51	42	190	
Below Ft. Scott, KS	2008	8	6	26	5.6	7.4	1101	1.9	1.08	0.50499	2.40499	0.22	25	102	621	
Below Ft. Scott, KS	2008	10	8	16	7.5	7.1	500	0.6	0.0499	0.33499	0.93499	0.07	10	10	283	
Below Ft. Scott, KS	2008	12	3	6	11.5	7.5	513	0.4	0.0499	0.12499	0.52499	0.04	4.99	3	286	
Below Ft. Scott, KS	2009	1	7	4	12.2	7.3	474	0.5	0.0499	0.20499	0.70499	0.08	10	10	267	

Appendix A.2 – Little Drywood Creek Historic Data

Collected by Missouri Department of Natural Resources and MEC Water Resources, 2001 - 2008

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
At Highway F	2001	5	24	16		7.8	201	0.72	0.02499	0.43	1.15	0.08		
At Highway F	2001	10	3	18		7.3	275							
At Highway F	2002	3	28	11		8.8	339	0.59	0.02499	0.02499	0.61	0.02499		
At Highway F	2002	8	29	26		7.4	314	1.84	0.42	0.02499	1.86	0.13		
At Highway F	2002	11	6	10		7.3	310	1.18	0.02499	0.02499	1.2	0.02499		
At 3 mi. SW of Nevada	2003	9	16	18	3.4	7.5	295	0.9	0.01499	0.03	0.93	0.1		19.8
At 4 mi. SSW of Nevada	2003	9	16	19	4.1	7.7	291	1	0.01499	0.03	1.03	0.1		15
At Highway F	2003	9	16	21	4.3	7.6	354	0.9	0.01499	0.03	0.93	0.08		12
At Highway F	2003	11	12	14.3		7.73	302	0.88	0.01499	0.00499	0.88	0.11		
At 5 mi. SSW of Nevada	2004	7	15	27.5	2.9	7	242	0.8	0.01499	0.32	1.13	0.11		
At 5.5 mi. SSW of Nevada	2004	9	1	23.5	5.7	7.6	325	0.63	0.01499	0.07	0.7	0.06		30.6
At 5.5 mi. SSW of Nevada	2004	9	20	19	2.5	7.4	348							
At 5.5 mi. SSW of Nevada	2004	10	6	13	5.5	7.5	383							
At 5 mi. SSW of Nevada	2004	11	4	11.6	7.1	7.8	451		0.01499	0.36	1.26	0.12		
At 5 mi. SSW of Nevada	2005	3	22	9.2	9.2	7.9	403		0.12	0.16	0.84	0.08		
At 5 mi. SSW of Nevada	2005	6	14	21.8	5.7	7.6	253		0.09	1.88	2.49	0.2		
At 5 mi. SSW of Nevada	2005	10	20	16.9	1.5	7.6	491		0.01499	0.00499	0.56	0.07		
At 5 mi. SSW of Nevada	2006	8	14	26	1.4		339							
At 5 mi. SSW of Nevada	2006	8	14	25.7	0.1		353							
At 5 mi. SSW of Nevada	2006	8	15	24.1	2		342							
At 5 mi. SSW of Nevada	2006	8	15	23.1	0.1		342							
At 5 mi. SSW of Nevada	2006	8	16	23.6	0.1		346							
At 5 mi. SSW of Nevada	2006	8	16	24	1.6		342							
At 5 mi. SSW of Nevada	2006	8	17	24.3	0.2		349							
At 5 mi. SSW of Nevada	2006	8	17	24.3	1.5		345							
At 5 mi. SSW of Nevada	2006	8	18	24.7	0.9		354							
At 5 mi. SSW of Nevada	2006	8	18	24.8	0.1		357							
At 5 mi. SSW of Nevada	2006	8	19	25.4	1.4		357							
At 5 mi. SSW of Nevada	2006	8	19	24.5	0.1		358							
At 5 mi. SSW of Nevada	2006	8	20	25.3	1.8		357							
At 5 mi. SSW of Nevada	2006	8	20	24.4	0.1		360							

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
At 5 mi. SSW of Nevada	2006	8	21	24.4	1.3		360							
At 5 mi. SSW of Nevada	2006	8	21	23.2	0.1		361							
At 5 mi. SSW of Nevada	2006	8	22	23	0.1		365							
At 5 mi. SSW of Nevada	2006	8	22	24.1	1.4		360							
At 5 mi. SSW of Nevada	2006	8	23	22.3	0.1		365							
At 5 mi. SSW of Nevada	2006	8	23	23.9	1.8		363							
At 5 mi. SSW of Nevada	2006	8	24	23.5	2		363							
At 5 mi. SSW of Nevada	2006	8	24	23.9	0.1		372							
At 5 mi. SSW of Nevada	2006	8	25	24	0.1		372							
At 5 mi. SSW of Nevada	2006	8	25	24.4	1.3		370							
At 5 mi. SSW of Nevada	2006	8	26	24.1	0.5		319							
At 5 mi. SSW of Nevada	2006	8	26	24.4	4		329							
At 5 mi. SSW of Nevada	2006	8	27	25.8	0.8		250							
At 5 mi. SSW of Nevada	2006	8	27	26	2.9		273							
At 5 mi. SSW of Nevada	2006	8	28	25.8	2.1		246							
At 5 mi. SSW of Nevada	2006	8	28	25.7	0.2		249							
At 5 mi. SSW of Nevada	2006	8	29	22.1	0.9		249							
At 5 mi. SSW of Nevada	2006	8	29	22.4	0.1		249							
At 5 mi. SSW of Nevada	2006	8	30	21.7	0.8		253							
At 5 mi. SSW of Nevada	2006	8	31	20.1	0.1		258							
At 5 mi. SSW of Nevada	2006	9	1	19.7	0.1		261							
At 5 mi. SSW of Nevada	2006	9	1	21	0.8		266							
At 5 mi. SSW of Nevada	2006	9	2	21	1.1		260							
At 5 mi. SSW of Nevada	2006	9	2	21.1	0.1		264							
At 5 mi. SSW of Nevada	2006	9	3	20.8	1.2		271							
At 5 mi. SSW of Nevada	2006	9	3	20.4	0.1		268							
At 5 mi. SSW of Nevada	2006	9	4	19.7	0.1		274							
At 5 mi. SSW of Nevada	2006	9	4	20.4	0.9		275							
At 5 mi. SSW of Nevada	2006	9	5	17.9	0.1		278							
At 5 mi. SSW of Nevada	2006	9	5	19.4	1.4		278							
At 5 mi. SSW of Nevada	2006	9	6	18.4	0.1		283							
At 5 mi. SSW of Nevada	2006	9	6	18.9	0.8		278							
At 5 mi. SSW of Nevada	2006	9	7	18.4	0		284							

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
At 5 mi. SSW of Nevada	2006	9	7	18.7	1		276							
At 5 mi. SSW of Nevada	2006	9	8	18.8	1.4		277							
At 5 mi. SSW of Nevada	2006	9	8	17.6	0		281							
At 5 mi. SSW of Nevada	2006	9	9	19	0		285							
At 5 mi. SSW of Nevada	2006	9	9	19.1	1.3		281							
At 5 mi. SSW of Nevada	2006	9	10	19.7	0		296							
At 5 mi. SSW of Nevada	2006	9	10	19.6	1.2		286							
At 5 mi. SSW of Nevada	2006	9	11	20	0.8		293							
At 5 mi. SSW of Nevada	2006	9	11	20	0		298							
At 5 mi. SSW of Nevada	2006	9	12	20.9	1		296							
At 5 mi. SSW of Nevada	2006	9	12	19.3	0		299							
At 5 mi. SSW of Nevada	2006	9	13	16.6	0.5		300							
At 5 mi. SSW of Nevada	2006	9	13	15.8	0.1		302							
At 5.5 mi. SSW of Nevada	2006	9	25	17	6.42	7.8	456		0.01499	0.02	0.56	0.03		4.84
At 5.5 mi. SSW of Nevada	2007	4	4	13.5	8	7.8	306		0.01499	0.41	1.12	0.09		11.4
At Highway F	2007	8	8	29.1	2.07		241							
At Highway F	2007	8	9	28	1.43		238							
At Highway F	2007	8	10	27.8	1.26		243							
At Highway F	2007	8	11	28	1.23		251							
At Highway F	2007	8	12	27.5	1.27		252							
At Highway F	2007	8	13	27.8	1.21		255							
At Highway F	2007	8	14	28	1.53		258							
At Highway F	2007	8	15	27.8	1.37		263							
At Highway F	2007	8	16	27.8	1.53		266							
At Highway F	2007	8	17	27.5	1.63		268							
At Highway F	2007	8	18	27.2	1.62		272							
At Highway F	2007	8	19	26.8	1.26		275							
At Highway F	2007	8	20	26.2	1.26		276							
At Highway F	2007	8	21	26.4	1.46		274							
At Highway F	2007	8	22	26.5	1.08		279							
At 5 mi. SSW of Nevada	2007	8	23	26	0.69		289							
At Highway F	2007	8	23	26.2	1.6		281							
At 5 mi. SSW of Nevada	2007	8	24	25.6	0.52		288							

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
At 5 mi. SSW of Nevada	2007	8	25	24.9	0.2		290							
At 5 mi. SSW of Nevada	2007	8	26	24.9	1.56		284							
At 5 mi. SSW of Nevada	2007	8	27	25.4	0.91		280							
At 5 mi. SSW of Nevada	2007	8	28	25.3	0.22		281							
At 5 mi. SSW of Nevada	2007	8	29	25.2	0.3		285							
At 5 mi. SSW of Nevada	2007	8	30	24.9	0.42		291							
At 5 mi. SSW of Nevada	2007	8	31	23.6	0.63		289							
At 5 mi. SSW of Nevada	2007	9	1	22.3	0.83		290							
At 5 mi. SSW of Nevada	2007	9	2	21	0.96		293							
At 5 mi. SSW of Nevada	2007	9	3	21	0.96		296							
At 5 mi. SSW of Nevada	2007	9	4	21.3	1.14		309							
At Sec.13, T34N, R32W	2008	7	15		6									
At Sec.13, T34N, R32W	2008	7	16		6									
At Sec.13, T34N, R32W	2008	7	17		5.8									
At Sec.13, T34N, R32W	2008	7	18		5.7									
At Sec.13, T34N, R32W	2008	7	19		5.5									
At Sec.13, T34N, R32W	2008	7	20		5.3									
At Sec.13, T34N, R32W	2008	7	21		5.1									
At Sec.13, T34N, R32W	2008	7	22		5									
At Sec.13, T34N, R32W	2008	7	23		5.1									
At Sec.13, T34N, R32W	2008	7	24		5									
At Sec.13, T34N, R32W	2008	7	25		4.6									
At Sec.13, T34N, R32W	2008	7	26		4.3									
At Sec.13, T34N, R32W	2008	7	27		5.6									
At Sec.13, T34N, R32W	2008	7	28		5.6									
At 5 mi. SSW of Nevada	2008	7	30		5.2									
At 5 mi. SSW of Nevada	2008	7	31		5.2									
At 5 mi. SSW of Nevada	2008	8	1		5.1									
At 5 mi. SSW of Nevada	2008	8	2		5									
At 5 mi. SSW of Nevada	2008	8	3		4.6									
At 5 mi. SSW of Nevada	2008	8	7		4.5									
At 5 mi. SSW of Nevada	2008	8	8		5									
At 5 mi. SSW of Nevada	2008	8	9		5									

Site	Year	Month	Day	Temp	DO	pH	SC	KJN	NH3N	NO3N	TN	TP	TSS	TRB
				deg C	mg/L		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
At 5 mi. SSW of Nevada	2008	8	10		5.4									
At 5 mi. SSW of Nevada	2008	8	11		5.6									
At 5 mi. SSW of Nevada	2008	8	12		5.6									
At 5 mi. SSW of Nevada	2008	8	13		5.7									
At 5 mi. SSW of Nevada	2008	8	14		5.6									
At 5 mi. SSW of Nevada	2008	8	15		5.7									
At 5 mi. SSW of Nevada	2008	8	16		5.6									
At 5 mi. SSW of Nevada	2008	8	17		5.4									
At 5 mi. SSW of Nevada	2008	8	18		5.4									
At 5 mi. SSW of Nevada	2008	8	19		5.2									
At 5 mi. SSW of Nevada	2008	8	20		5.1									
At 5 mi. SSW of Nevada	2008	8	21		4.7									
At 5 mi. SSW of Nevada	2008	8	22		4.7									
At 5 mi. SSW of Nevada	2008	8	23		4.4									
At 5 mi. SSW of Nevada	2008	8	24		4.2									
At 5 mi. SSW of Nevada	2008	8	25		4.5									
At 5 mi. SSW of Nevada	2008	8	26		4.3									
At 0.8 mi North of Hiwy 54	2008	8	27	25	5.01	7.2	1910	0.52	0.2	6.91		1.27		
At 0.8 mi North of Hiwy 54	2008	8	27	22.3	4.54	7.2	2090	0.63	0.26	6.96		1.35		
At 0.8 mi North of Hiwy 54	2008	8	27	23.3	3.65	7.4	525	0.6	0.09	0.34		0.15		
At 0.8 mi North of Hiwy 54	2008	8	27	22.3	3.53	7.3	486	0.49	0.08	0.22		0.06		
At Marmaton R. & CR 334	2008	8	27	26.3	6.47	7.8	1110	0.33	0.01499	0.76		0.18		
At Marmaton R. & CR 334	2008	8	27	24.1	5.62	7.8	1180	0.46	0.01499	1.23		0.27		
WWTP Composite Sample	2008	8	27	27.6	6.13	7.5	1190	0.02499	0.64	16.1		3.5		

Note: These data are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development because they were collected in accordance with required quality assurance procedures and department sampling protocols.

Empty cell means no data available.

C = temperature in degrees Celsius
DO = Dissolved Oxygen
Hwy = Highway
SC = Specific Conductivity
KJN = Kjeldahl Nitrogen
NH3N = Ammonia as N
NO3N =nitrate +nitrite as nitrogen
TN = Total Nitrogen
TP = Total Phosphorus
TSS = Total Suspended Solids
TRB = Turbidity
TDS = Total Dissolved Solids
BOD = Biochemical Oxygen Demand

Detection limits and non-detects are expressed as "less-than" numbers and show up in this list as those data ending in 99. Example: <2 will appear as 0.99.

Appendix B

Development of Nutrient and Sediment Targets Using Reference Load Duration Curves

Overview

This procedure is used when a lotic system is placed on the 303(d) impaired waters list for an impairment that can be attributed to nutrients and sediment, and the designated use being addressed is the protection of aquatic life. In cases where EPA-approved state numeric criteria for the impaired stream is not available, a reference approach is used. For nutrients, the targets for pollutant loading are the EPA-recommended ecoregion nutrient criteria for the specific ecoregion in which the water body is located (EPA 2000). These targets are based on the 25th percentile of all total nitrogen and total phosphorus data gathered from the ecoregion, where data are not directly influenced by permitted dischargers. For sediment, the target was derived based on a similar reference approach by targeting the 25th percentile base load concentration of total suspended solids measurements collected by the USGS in the ecological drainage unit, or EDU, where the water body is located.

If a flow record for the impaired stream is not available a synthetic flow record is needed. To develop a synthetic flow record a user should calculate an average of the log discharge per square mile of USGS gaged rivers for which the drainage area is contained within the EDU (Table B.1). From this synthetic record develop a flow duration and build a load duration curve for the pollutant within the EDU. This appendix describes how the criteria for total nitrogen, total phosphorus and total suspended solids are expressed in this TMDL.

Methodology

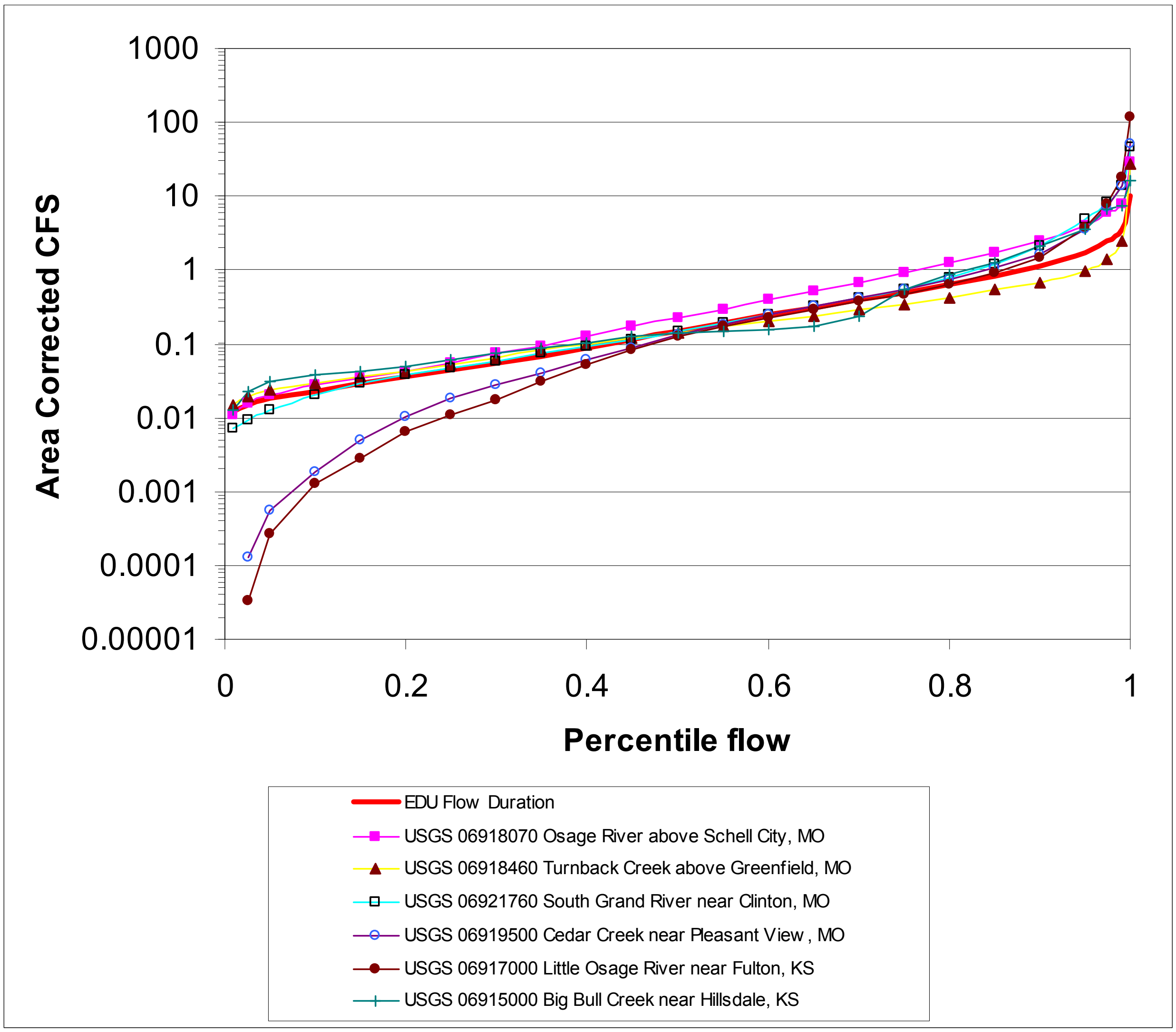
The first step in this procedure is to gather available nutrient and total suspended solids data within the ecoregion of interest (Tables B.2 and B.3). These data, along with the instantaneous flow measurement taken at the time of sample collection for the specific date, are required to develop the load duration curve. Both dates and nutrient or total suspended solids concentrations are needed in order to match the measured data used with the synthetic EDU flow record.

Secondly, collect average daily flow data from gages with a variety of drainage areas for a period of time to cover the data record. From these flow records normalize the flow to a per square mile basis. Average the log transformations of the average daily discharge for each day in the period of record. For each gage record used to build the synthetic flow record calculate the Nash-Sutcliffe value to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square mile is then used to develop the load duration curve for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow (typically 20 years or more). Figure B.1 presents a graph of the synthetic normalized flow duration curve and normalized flow duration curves for the four USGS gages (Table B.1) used in the analysis.

Table B.1 USGS gages used to develop synthetic flow regime for the Central Plains/Osage/South Grand EDU (10/2/1989-6/30/2009)

Gage Number	Gage Name	Drainage Area (mi^2)	Nash-Sutcliffe
USGS 06918070	Osage River above Schell City, MO	5410	55%
USGS 06918460	Turnback Creek above Greenfield, MO	870	59%
USGS 06921760	South Grand River near Clinton, MO	1270	33%
USGS 06919500	Cedar Creek near Pleasant View, MO	420	30%
USGS 06917000	Little Osage River near Fulton, KS	295	11%
USGS 06915000	Big Bull Creek near Hillsdale, KS	147	77%

Figure B.1 Synthetic flow duration curve, Central Plains/Osage/South Grand EDU



The next step was to collect previously measured water quality data from within the ecoregion. Measured total nitrogen and total phosphorus concentrations are adjusted so their median is equal to the EPA-recommended ecoregion nutrient criteria for each nutrient. This is accomplished by subtracting from the measured data the difference between the EPA-recommended ecoregion total nitrogen or total phosphorus criterion and the median from the measured data. This results in the data retaining most of its natural variability yet having a median which meets the EPA-recommended ecoregion nutrient criteria. Measured total suspended solids concentrations are adjusted so that their median is equal to the 25th percentile base load concentration of total suspended solids measurements collected by the USGS in the EDU. This is accomplished by subtracting from the measured data the difference between the 25th percentile target and the median from the measured data, and results in the data retaining most of its variability while having a median that meets the 25th percentile target. Where these adjustments would result in a negative concentration for each parameter, the minimum measured concentration is substituted.

Figures B.2. through B.4. show examples of this process where the solid line is the measured distribution of the natural log of nutrient and total suspended solids concentration with the natural log flow, and the dashed line represents a data distribution (the adjusted data) which would comply with the EPA-recommended ecoregion total nitrogen and total phosphorus criteria (or the 25th percentile EDU target, in the case of total suspended solids).

Figure B.2 Graphic representation of data adjustment for total nitrogen (TN)

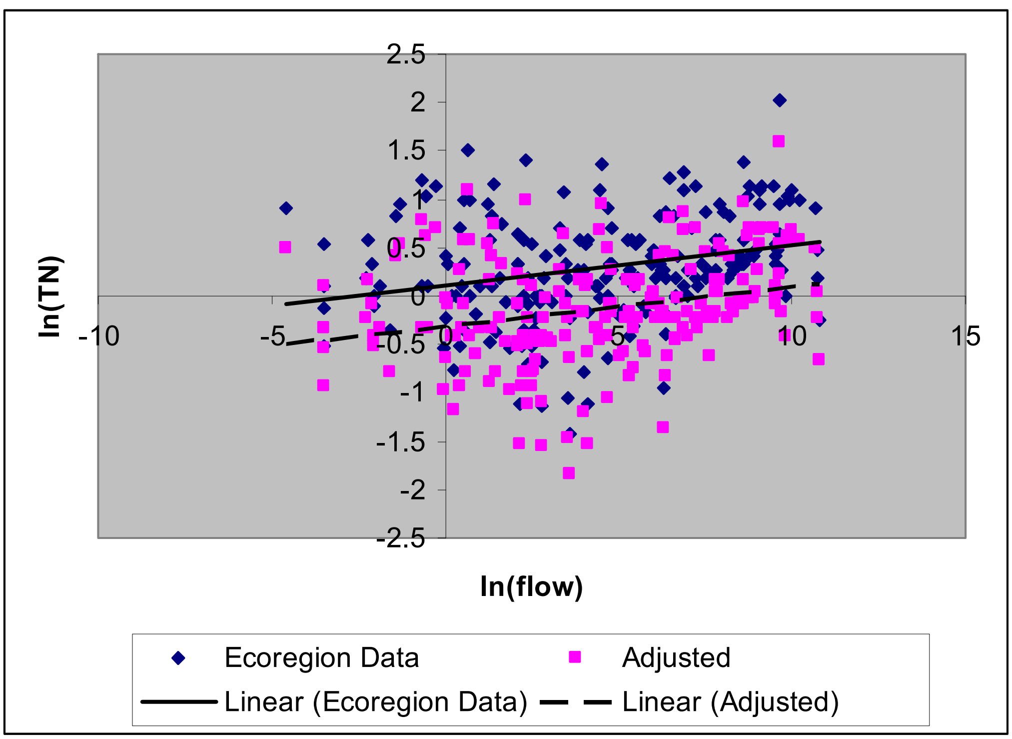


Figure B.3 Graphic representation of data adjustment for total phosphorus (TP)

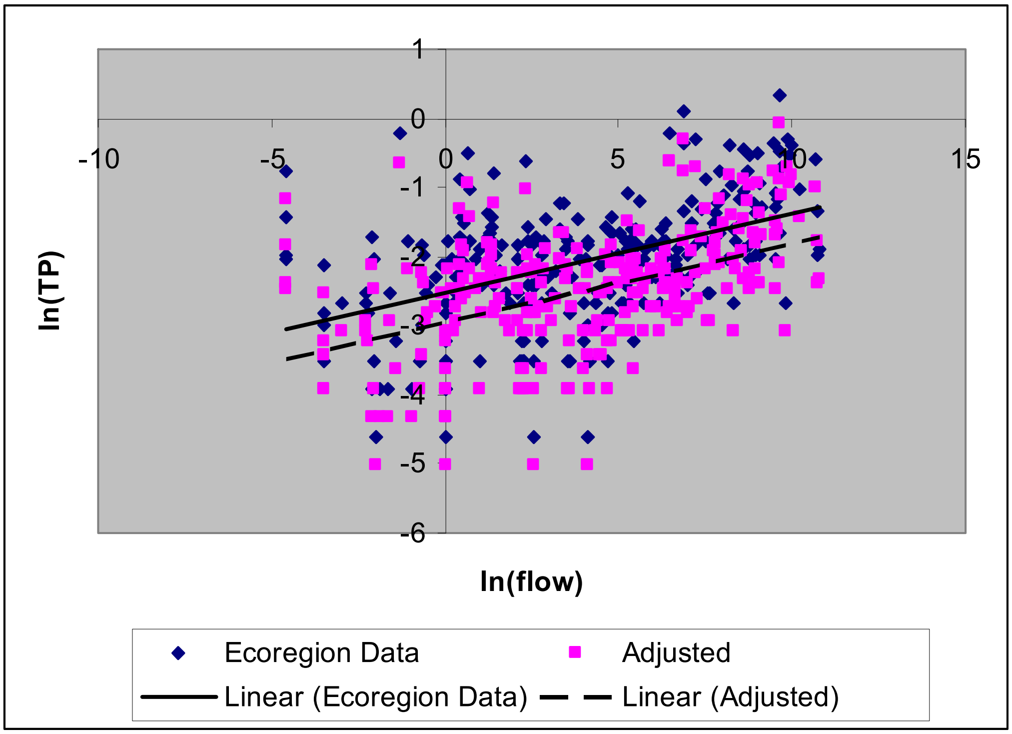
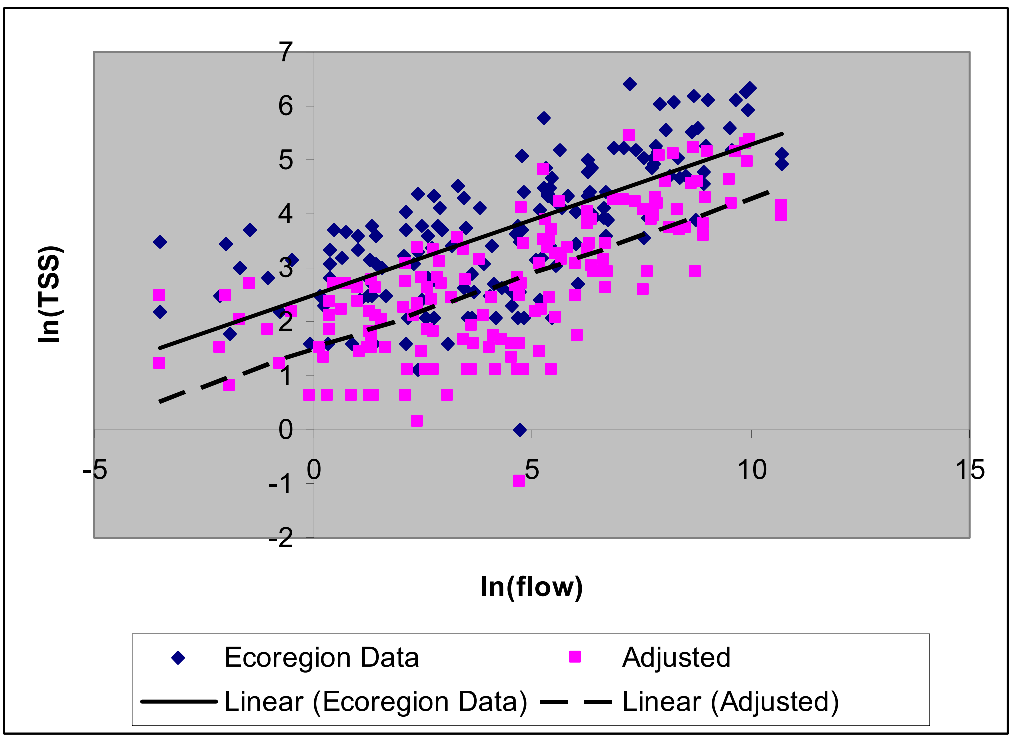


Figure B.4 Graphic representation of data adjustment for total suspended solids (TSS)



The next step was to calculate the total nitrogen and total phosphorus – discharge relationships for the ecoregion using the adjusted data, and to calculate the total suspended solids – discharge relationship for the appropriate EDU using the adjusted data. This is natural log transformed data for the yield (pounds/day) and the instantaneous flow (cfs). Figures B.4 through B.6 show these relationships for the Marmaton River TMDL.

Figure B.4 Load / flow relationship used to set TN load duration curve

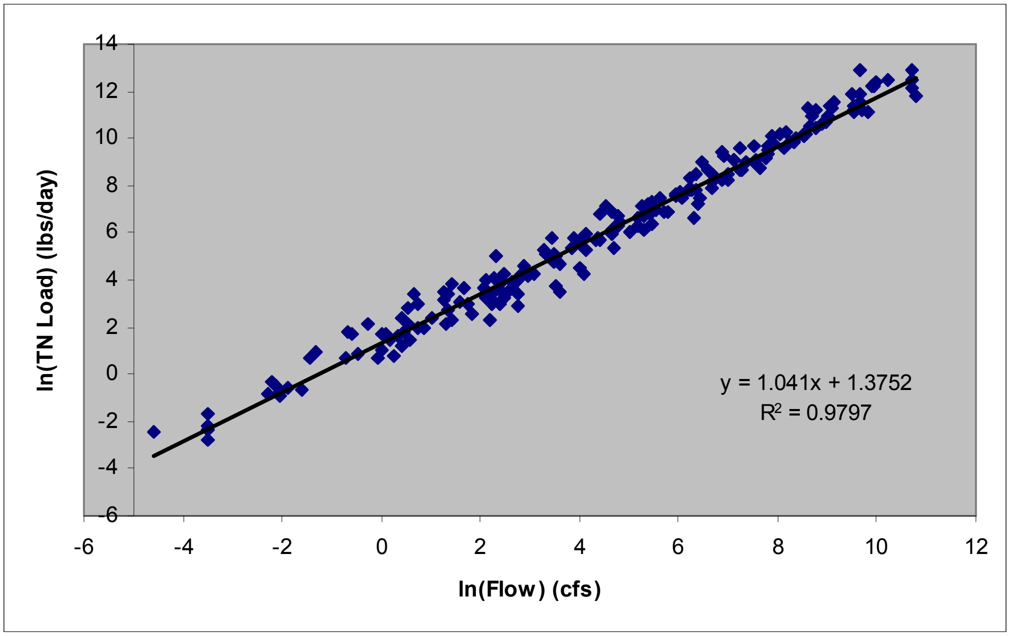


Figure B.5 Load / flow relationship used to set TP load duration curve

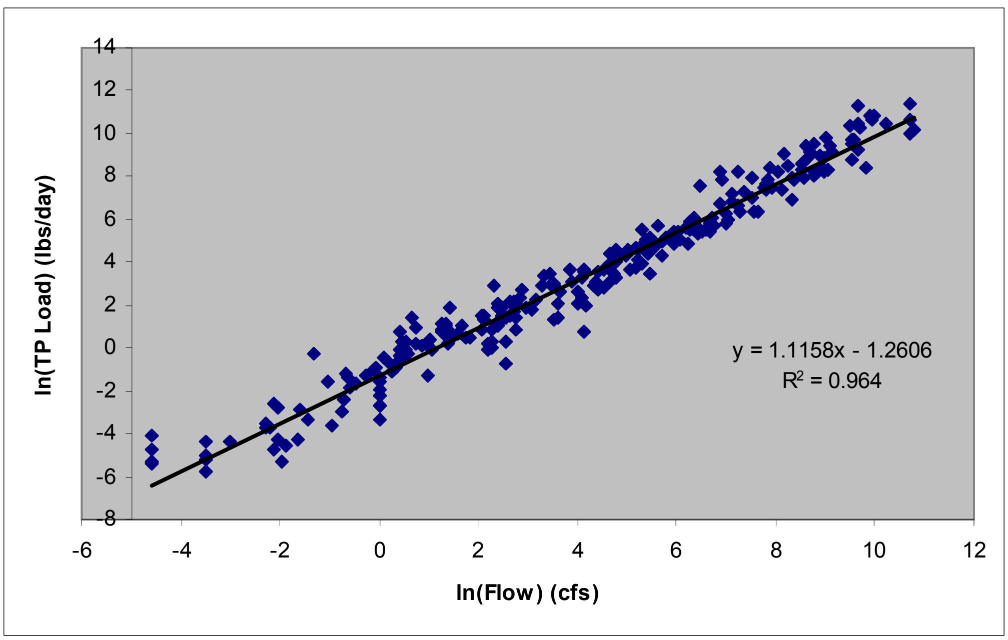
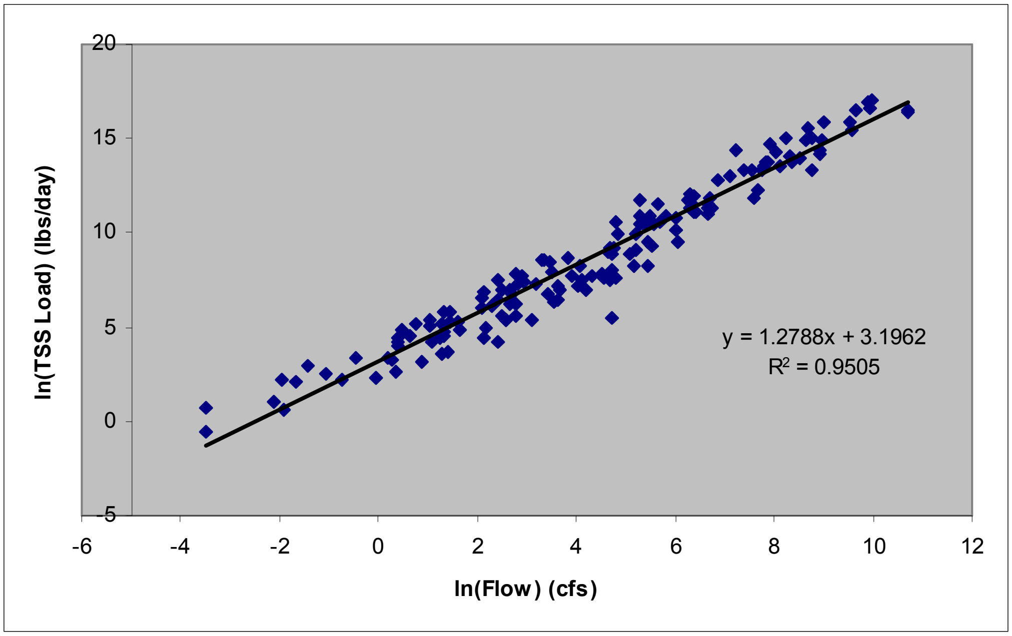


Figure B.6 Load / flow relationship used to set TSS load duration curve



This relationship was used to develop a load duration curve for which the relationships between flow and nutrient distribution, and flow and total suspended solids, are taken into account. In these load duration curves the targeted concentrations are allowed to change at different percentiles of flow exceedance. However, meeting the load duration curves will result in a water body in which the median nutrient concentrations are equal to the EPA-recommended ecoregion criteria, and the median total suspended solids concentrations are equal to the 25th percentile of data collected in that EDU.

To apply this process to a specific watershed entails using the individual watershed data compared to the TMDL curve that has been multiplied by the watershed area (mi^2). Data from the impaired segment is then plotted as a load (pounds/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis. These data points do not have to be collected at the segment outlet. The spreadsheet applies to an outlet flow (percentile flow exceedance) to the concentration based on the synthetic flow estimate for the specific date the sample was taken.

The resulting load duration curve with plotted site-specific measured data can now be used to target implementation by identifying flows in which nutrient and total suspended solids concentrations are higher than would be expected in a stream meeting the recommended criteria. See load duration curves in the TMDL, Figures 6 through 8.

References

EPA (U.S. Environmental Protection Agency). 2000. Ambient Water Quality Criteria Recommendations Information Supporting the Development of State and Tribal Nutrient Criteria Rivers and Streams in Nutrient Ecoregion IX, EPA 822-B-00-019, 91p.

Table B.2 USGS gaging stations gaging stations used to

collect water quality data

Gage#	Name	Drainage Area (mi^2)
06918070	Osage River above Schell City, MO	5410
06919500	Cedar Creek near Pleasant View, MO	420
06919950	Brush Creek above Collins, MO	82
06921590	South Grand River at Archie, MO	356
06921720	Big Creek near Blairstown, MO	414
06922190	West Fork Tebo Creek near Lewis, MO	No Data
3844410942043	South Trib. Muddy Creek nr Harrisonville, MO	No Data
3845250942233	Muddy Creek nr Harrisonville, MO	No Data
3846130942231	North Trib. Muddy Creek nr Harrisonville, MO	No Data
06921582	South Grand River below Freeman, MO	150
06920580	Weaubleau Creek near Collins, MO	No Data

Table B.3 Nutrients, suspended solids and instantaneous discharge for reference targeting Data collected by USGS and provided by EPA

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
USGS 06918070 Osage River above Schell City, MO				
11/8/1989	1400		1.2	0.16
1/11/1990	802			0.08
3/8/1990	8470		3	0.14
5/8/1990	5360		1.4	0.15
7/12/1990	1080		1	0.09
9/6/1990	1.4		1	0.1
5/8/1991	1210		2	0.22
7/18/1991	540		0.39	0.17
9/5/1991	500		2.3	0.16
11/5/1991	200		0.66	0.07
1/9/1992	720		2.3	0.1
3/3/1992	380		1.4	0.1
5/6/1992	500		1.4	0.07
7/9/1992	16000		1.3	0.5
9/2/1992	300			0.07
11/19/1992	13700		1.5	0.34
1/12/1993	4160		1.3	0.07
3/10/1993	6440		1.5	0.13
5/5/1993	7740		1.6	0.14
7/27/1993	45300		1.2	0.26
9/28/1993	48200		0.78	0.15
11/29/1994	13900	270	1.7	0.28
3/7/1995	1430		1.1	0.11
4/13/1995	1860		1.2	0.17
5/16/1995	13900		1.4	0.13
6/27/1995	45400	140	1.6	0.14

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
8/22/1995	822	82	1.5	0.15
11/7/1995	228	30		0.1
4/1/1996	226		1.1	0.12
5/7/1996	15500		7.5	1.4
6/19/1996	5960	480	2.8	0.46
8/6/1996	493		1.4	0.16
11/5/1996	2110	50	0.82	0.08
3/4/1997	15400		1.9	0.19
4/15/1997	27800		2.7	0.36
5/13/1997	1100		1.3	0.14
6/24/1997	2480	190	1.8	0.18
8/13/1997	80		1.1	0.08
11/6/1997	401	31		
6/8/1998	545	150		
3/9/1999	13300		3.1	0.7
4/6/1999	1150			0.1
5/17/1999	18600		1	0.07
6/7/1999	7920	195	1.6	0.25
8/25/1999	148			0.14
11/1/1999	253	21		0.12
3/20/2000	8830		2.6	0.39
4/11/2000	662			0.1
5/22/2000	300	61	0.91	0.13
6/5/2000	385		1.5	0.17
7/24/2000	3560		2.3	0.67
11/27/2000	177	11	0.86	0.07
3/21/2001	9090		3.1	0.28
4/18/2001	2720		1.8	0.19
5/21/2001	5450		4	0.64
6/13/2001	5080		1.4	0.22
11/28/2001	185	24		0.09
3/11/2002	621	50	0.82	0.09
4/15/2002	949	183	1.1	0.26
5/22/2002	6400	49	1.5	0.16
6/17/2002	5600	252	1.8	0.35
7/24/2002	229	E 90[1]	1.2	0.17
11/6/2002	93	13		0.05
3/17/2003	538	75	1.3	0.13
4/15/2003	211	78		0.15
5/13/2003	2700	426	2.6	0.47
6/17/2003	1220	188	2	0.3
7/9/2003	524	120	1.3	0.2
11/4/2003	113	32		0.08
3/9/2004	44000	164	2.5	0.56
4/19/2004	860	49		0.1
5/11/2004	783	62	0.97	0.12

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
6/7/2004	567	83	1.2	0.17
7/21/2004	2310	130	1.2	0.22
11/15/2004	5000	109	1.5	0.31
3/28/2005	1950	35	1.3	0.08
4/12/2005	3780	432	1.4	0.38
5/24/2005	3130	256	2.4	0.33
6/28/2005	7400	120	1.5	0.29
7/25/2005	1600	178	1.4	0.27
11/28/2005	159	23		0.07
3/22/2006	792	36	0.99	0.11
4/19/2006	330	76	0.85	0.15
5/22/2006	2590	172	1.6	0.29
6/20/2006	259	68	1.2	0.16
11/13/2006	37	18	0.8	0.06
2/26/2007	6430	264	3.1	0.58
3/6/2007	1880	156	2.4	0.41
4/16/2007	21700	560	3	0.67
5/7/2007	20500	370	2.7	0.59
6/26/2007	2420	156	1.6	0.25
7/24/2007	8320	448	2	0.6
11/5/2007	179	58	1.2	0.17
3/17/2008	3400	111	1.2	0.13
4/22/2008	4330	108	1.4	0.17
5/28/2008	19900	532	2.8	0.74
6/3/2008	15700	456	2.6	0.63
7/21/2008	785	50	1.2	0.13
10/14/2008	587	55	0.67	0.14
3/17/2009	4140	152	1.3	0.2
4/7/2009	7560	96	1.6	0.17
5/19/2009	14400	176	1.6	0.31
6/2/2009	2440	140	1.3	0.21
USGS 06919500 Cedar Creek near Pleasant View, MO				
10/14/2008	8.8	< 15[2]	E 0.33[1]	E 0.03[1]
11/3/2008	13	< 15[2]		E 0.03[1]
12/1/2008	16	< 15[2]	E 0.32[1]	E 0.04[1]
1/26/2009	34	< 15[2]	0.35	E 0.03[1]
2/3/2009	37	< 15[2]	0.24	E 0.03[1]
3/17/2009	66	< 15[2]		E 0.03[1]
4/7/2009	235	< 15[2]	0.73	0.04
5/19/2009	430	< 30[2]	1.2	0.1
6/2/2009	106	< 15[2]	1	0.06
10/14/2008	8.8	< 15[2]	E 0.33[1]	E 0.03[1]
11/3/2008	13	< 15[2]		E 0.03[1]
12/1/2008	16	< 15[2]	E 0.32[1]	E 0.04[1]
1/26/2009	34	< 15[2]	0.35	E 0.03[1]
2/3/2009	37	< 15[2]	0.24	E 0.03[1]

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
3/17/2009	66	< 15[2]		E 0.03[1]
4/7/2009	235	< 15[2]	0.73	0.04
5/19/2009	430	< 30[2]	1.2	0.1
6/2/2009	106	< 15[2]	1	0.06
USGS 06919950 Brush Creek above Collins, MO				
5/25/1994	13			< 0.01[1]
9/21/1994	0.39			0.02
5/23/1995	62			0.01
USGS 06921590 South Grand River at Archie, MO				
6/14/2007	49	22	1.8	0.13
7/13/2007	59	30	1.7	0.13
9/13/2007	5.2	12	2.1	0.16
11/30/2007	4.1	< 10[2]	3.2	0.45
1/17/2008	61	15	1.8	0.16
3/20/2008	579	128	2.4	0.22
5/14/2008	280	180	1.8	0.3
7/23/2008	14	17	1	0.09
9/11/2008	11	27	0.92	0.17
10/9/2008	13	< 15[2]	0.71	0.09
1/6/2009	121	< 15[2]	1.3	0.06
3/27/2009	200	130	1.3	0.17
5/19/2009	118	40	1.4	0.14
USGS 06921720 Big Creek near Blairstown, MO				
10/9/2008	11	78		0.21
11/4/2008	62		0.85	0.17
3/24/2009	198	324	1.2	0.34
5/19/2009	218	76	1.8	0.2
USGS 06922190 West Fork Tebo Creek near Lewis, MO				
10/13/1989	1			0.07
11/9/1989	1			0.03
12/7/1989	1			0.04
1/11/1990	1			0.02
2/8/1990	2.7			0.03
3/8/1990	9.3		0.6	0.03
4/4/1990	9.6			0.03
5/7/1990	9.6		1	0.04
6/7/1990	9.5		0.7	0.03
7/12/1990	9.6		1.8	0.07
8/10/1990	9			0.04
9/6/1990	1		0.8	0.06
10/16/1990	1			< 0.01[2]
11/7/1990	1			0.02
12/5/1990	1			0.02
1/9/1991	1			0.02
3/6/1991	1			0.02
4/17/1991	1			0.03

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
5/7/1991	8		1.4	0.08
6/4/1991	1		1.5	0.03
7/18/1991	0.1			0.07
8/12/1991	0			0.13
9/6/1991	0			0.14
USGS 3844410942043 South Trib. Muddy Creek nr Harrisonville, MO				
4/29/1992	0.19	20		0.02
5/20/1992	0.03	32	1.1	0.05
6/17/1992	0	132		0.24
8/27/1992	0.03		1.7	0.12
9/29/1992	0.05			0.07
11/4/1992	0.1		1.2	0.08
12/8/1992	0.13		0.9	0.13
1/27/1993	1.6		1.1	0.24
2/24/1993	0.2		0.7	0.08
3/24/1993	0.5		1.1	0.05
USGS 3845250942233 Muddy Creek nr Harrisonville, MO				
4/30/1992	0.14	31		0.01
5/20/1992	0.24	40	2.3	0.04
8/27/1992	0.01		2.5	0.47
12/8/1992	0.11		1.8	0.06
1/27/1993	1.7		2.7	0.22
2/24/1993	0.12		1.4	0.02
3/24/1993	0.13		1	0.03
USGS 3846130942231 North Trib. Muddy Creek nr Harrisonville, MO				
4/29/1992	0.48	9		0.03
5/20/1992	0.15	6	1.1	0.02
6/17/1992	0.03	9	0.88	0.03
8/27/1992	0.03		0.6	0.06
11/4/1992	0.27		2.6	0.8
12/8/1992	0.77		3.1	0.1
1/27/1993	3.5		2.6	0.25
2/24/1993	0.52		3.3	0.16
3/24/1993	0.56		2.8	0.08
USGS 06921582 South Grand River below Freeman, MO				
1/14/1998	95	10		
6/1/1998	112	1		
8/20/1998	3.6	23		
11/18/1998	76	14	1.1	0.07
12/3/1998	150		0.81	0.19
1/26/1999	56	12	1.3	0.07
2/24/1999	84		0.97	E 0.05[1]
3/24/1999	56		0.46	E 0.04[1]
4/14/1999	60		E 0.33[1]	< 0.05[2]
5/17/1999	995		3	0.7
6/16/1999	27	92	2	0.2

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
7/28/1999	4.4			0.1
8/11/1999	4.2	22	0.69	0.1
9/15/1999	6.3		0.58	0.07
10/21/1999	4			0.09
11/8/1999	3.5	12		0.18
12/8/1999	34		1.2	0.17
1/5/2000	11	3	1.2	0.09
2/16/2000	5.8		0.94	0.08
3/14/2000	12		0.6	0.09
4/11/2000	11		0.5	0.07
5/23/2000	16	75	1	0.14
6/13/2000	15		0.99	0.17
7/18/2000	4.2	37		0.14
8/17/2000	0.89			0.12
9/13/2000	0.53			0.14
10/19/2000	2.1		2.7	0.36
11/20/2000	2.4	< 10[2]	0.83	0.13
12/12/2000	1.7		1.4	0.15
1/16/2001	10	22	4.1	0.54
3/1/2001	94		3.9	0.12
3/21/2001	84		3	0.12
4/11/2001	648		3.4	0.81
5/9/2001	32	73	1.4	0.18
6/21/2001	952		3.6	1.12
7/18/2001	8.3	56	0.94	0.13
8/14/2001	1.8		0.69	0.12
9/6/2001	1.1		1.4	0.17
10/17/2001	46	61	1.3	0.23
11/13/2001	3.7	16	E 0.62[1]	0.15
12/18/2001	4.9	20	1.2	0.11
1/23/2002	3.8	12	2.3	0.21
2/20/2002	125	82	1.4	0.19
3/4/2002	22	< 10[2]	0.94	0.08
4/23/2002	120	160	2	0.24
5/15/2002	239	108	1.7	0.2
6/11/2002	19	40	0.98	0.1
7/10/2002	1.6	40		0.11
8/13/2002	8.2	41	0.9	0.16
9/25/2002	0.62	23	1.1	0.09
10/21/2002	1.3	10	E 0.47[1]	0.07
11/14/2002	0.95	< 10[2]	E 0.58[1]	0.12
12/13/2002	1.4	< 10[2]		0.08
1/7/2003	1.5	22		0.13
2/11/2003	1.5	28	2	0.41
3/5/2003	1.9	24	4.5	0.6
3/7/2003	1.5			

Date	Flow (cfs)	TSS* (mg/L)	TN (mg/L)	TP (mg/L)
3/7/2003	1.5			
4/10/2003	2.8	28	E 1.1[1]	0.15
5/30/2003	2.8	36		0.15
6/19/2003	3.8	43	1.1	0.17
7/23/2003	0.35	17		0.17
8/22/2003	0.12	12		0.18
9/23/2003	1.2	12	1	0.13
11/10/2003	2.9	11		0.09
1/13/2004	8.3	< 10[2]	1.9	0.13
2/23/2004	23			
3/10/2004	107	44	2.5	0.13
5/7/2004	24	30		0.11
7/20/2004	17	44	1.2	0.17
9/22/2004	18	60	1.5	0.23
11/3/2004	105	38	1.2	0.21
1/11/2005	412	56	1.6	0.16
3/22/2005	39	13		0.1
5/6/2005	16	16	E 0.51[1]	0.07
7/22/2005	12	44	0.69	0.11
9/30/2005	8	25	1.4	0.16
11/15/2005	3.8	15		0.24
1/13/2006	3.6	< 10[2]	1.8	0.19
2/27/2006	3			
3/17/2006	14	37	0.79	0.18
5/17/2006	15	29	0.94	0.1
7/14/2006	28	92	1.6	0.29
9/11/2006	2.1	39	1	0.17
11/27/2006	1.5	17	0.6	0.18
1/12/2007	12	11	1.7	0.16
2/9/2007	31	14	2.9	0.29
3/28/2007	33	42	1	0.15
4/17/2007	194	90	1.8	0.15
5/4/2007	1380	600	3.1	0.75
USGS 06920580 Weaubleau Creek near Collins, MO				
5/8/2007	111	13	0.53	E 0.03[1]

1 Where data are estimated (E) the estimate was used in calculations.
2 Where data was less than the limit of detection [<] a value one half the limit of detection was used
*NOTE: Data was originally recorded as nonfilterable residue (NFR) by the U.S. Geological Survey. This has been changed to total suspended solids (TSS) for consistency within this document. NFR and TSS are synonymous.

Appendix C
QUAL2K Water Quality Model for Marmaton River

I. Model Setup

QUAL2K is a steady-state stream water quality model that primarily simulates DO and water quality parameters that influence diurnal DO fluctuations. It assumes that the major transport mechanisms are significant only in the direction of flow. QUAL2K conceptualizes a river system as a sequence of completely mixed reactors or computational elements. As a steady-state model, it is fairly limited in characterizing river systems where transient conditions are significant.

A QUAL2K model was developed for Marmaton River. The model was calibrated for the flow and water quality data measured on Aug. 27, 2008. The succeeding sections outline the details of the model setup, model inputs, calibration, and simulation results.

Hydraulics. QUAL2K allows the input of the hydraulic characteristics of a river as empirical relations of mean water depths, velocities and flow widths as power functions of discharge. In the absence of stream measurements during the sampling period, depths and velocities as functions of discharge were developed using the historical rating measurements of four USGS gages along the Marmaton River. The depth-discharge and velocity-discharge functions were developed from recent rating measurements for the gages at Marmaton near Marmaton, Mo. (USGS06917380), Marmaton near Richards, Mo. (USGS06917560), Marmaton near Nevada (USGS06918060), and Marmaton below Nevada (USGS06918065). Table 1 shows the set of river hydraulic characteristics derived from the analysis of the USGS rating measurements.

Table 1. Hydraulic characteristics at USGS gage locations in Marmaton River.

Marmaton Gages	**Drainage Area sq. mi.**	**Velocity (mps)**		**Depth (m)**	
		Coefficient	**Exponent**	**Coefficient**	**Exponent**
Near Marmaton	292	0.3422	0.2876	0.2753	0.3711
Near Richards	455	0.3107	0.1750	0.3095	0.4713
Near Nevada	1074	0.3038	0.2061	0.2418	0.4360
Below Nevada	1090	0.4043	0.4101	0.2265	0.2612
All Gages		0.3244	0.2515	0.2747	0.4097

River Discretization. The model domain for Marmaton River is the segment beginning from the confluence of Marmaton River with Wolverine Creek just upstream of the old USGS gage near Fort Scott, KS and extends to the confluence of Marmaton with Little Osage. The domain was discretized into 130 computational segments with an average length of 500 meters. The summary of the basin and reach characteristics is shown in Table 2.

Table 2. Marmaton modeled sub-basins and reach characteristics.

Basin	Area sq.mi.	Flow Type[1]	Flow to Reach	Reach Length (mi.)
1	6.79	Uniform Lateral	1	5.26
2	28.74	Tributary		
3	9.29	Uniform Lateral	2	7.60
4	16.06	Tributary		
6	9.23	Uniform Lateral	3	1.21
7	3.91	Tributary	2	7.60
	0.57	Uniform Lateral	4	3.21
	0.20	Tributary		
8	175.97	Tributary		
9	11.75	Uniform Lateral	5	5.12
10	15.41	Tributary		
11	386.0	Tributary	6	1.33
12	11.50	Uniform Lateral	7	6.02
13	12.26	Tributary		
14	2.55	Uniform Lateral	8	2.52
15	23.58	Tributary		
16	4.70	Tributary	9	6.22
17	6.65	Uniform Lateral		
18	8.08	Tributary		
19	3.96	Uniform Lateral	10	2.57

[1] *Tributary modeled as point source, uniform lateral flow as diffuse flow.*

Boundary Conditions and Lateral Inflows. The upstream boundary of the Marmaton model is the confluence of Marmaton with Wolverine Creek near Fort Scott, KS. For modeling purposes, the lateral inflows (both tributary and diffuse) into the modeled segments were estimated using a mass balance between the flows at the USGS gages near Marmaton, KS, near Richard, Mo. and near Nevada, Mo. The net lateral inflow into the modeled reaches was estimated as the difference between the flows measured at these gages. The flows were then proportioned to the various contributing sub-basins based on drainage area. Figure 1 shows the hourly flows recorded at the USGS gages near Richard, Mo. and near Nevada, Mo. for August 2008. On August 27, 2008, the daily flows at Marmaton, Richards and Nevada were 2.4, 6.2 and 35 cfs, respectively.

Meteorological Forcing Functions. Hourly data from the automated weather station in Lamar in Barton County, MO were used to develop the meteorological forcing functions for the models. Although there is a NWS cooperative weather station at the Nevada WWTP, Mo. only daily data for temperature is available through the National Climate Data Center. The water quality model requires hourly data for air temperature, dew point, wind speed and cloud cover.

Water Quality. The water quality parameterization was based on the results of the single-station diurnal DO analysis. In addition, the model requires specification of the loadings at the upstream and tributary/point sources. Tributary and diffuse loadings were estimated based on historical

measurements in the basins and in an adjacent basin (Little Osage River). The summary of historical water quality measurements on the main stem and tributaries of the Marmaton River (spreadsheets from MoDNR, c/o Bill Whipps) served as basis for deriving loading inputs. For the upstream boundary conditions, historical water quality measurements from a KDHE monitoring station (SC208) near Fort Scott, KS were used. Sensitivity analysis of the calibration model indicated that errors in specifying the loading inputs do not have a major impact on the diurnal DO fluctuation as compared to the sediment oxygen demand (SOD). Kinetic rate coefficients used in the model where initially specified following suggested values in the literature (e.g. Bowie et. al, 1985). The values were adjusted as necessary in the calibration run to get reasonable match between measured and simulated water chemistry.

II. Model Calibration

The Marmaton model was calibrated using the measured data on Aug. 27, 2008. Water chemistry data for Aug. 25, 2008 were used to set the initial conditions of the calibration run. In general, the calibration process involved estimating the SOD that could account for the diurnal fluctuation of DO at the sampling sites. Based on the single-station analysis of the continuous DO measurements, results indicated that benthic processes may contribute significantly to the fluctuation of DO observed under critical low flow conditions. Preliminary model runs indicated that the contribution of water column processes seems to be small relative to the contribution of benthic processes in explaining the observed variability of DO at the sampling sites. It should be noted that prior to the sampling period, oxygen demanding materials may have accumulated in the system. The continuous accumulation and decay of oxygen demanding materials in the benthos cannot be represented in a steady-state model. QUAL2K cannot represent the temporal changes in SOD due to varying flow and loading conditions prior to a specific steady-state run. Moreover, since QUAL2K does not allow initialization of the benthic process, additional SOD was prescribed for the calibration run. The SOD rate was adjusted until a reasonable match between simulated and measured diurnal DO curve is obtained.

Although water chemistry data were available from the spring sampling, the Marmaton model was not validated with those data. High flows during the spring sampling, which was conducted on the intervening days between major storm events, preclude a validation model for that period. For the purposes of this study, the set of calibration parameters developed for the Little Osage model (described in a previous report) were used. Minor adjustments were made to the parameters considering possible differences in site conditions.

Simulation Results. The modeling results are summarized in Table 3 and Figures 3 through 5. For each site, model predictions of DO were compared with the observed data. In comparing model predictions with observed data, it should be noted that the model predictions are average concentrations for a given computational segment while the measured data are instantaneous values at specific locations. Qualitative comparisons were made as compared to more rigorous quantitative assessments using statistical approaches. Table 3 and Figure 4 show that the water quality model did fairly well in simulating the diurnal DO data at the sampling sites. Deviations of the DO model predictions (minimum, maximum and mean diurnal DO) for the Marmaton sites were within 10 percent of the measured data. The comparison of the model predicted longitudinal variation of DO with the measured data is shown in Figure 5.

III. Model Application

The calibrated model described above was used to determine the reduction in SOD necessary to meet the water quality standards (WQS) for DO. The model was modified with 7Q10 flows at the upstream, downstream, tributaries and lateral inflow boundaries. Records from the USGS gage (USGS06918070) near Fort Scott, KS and the gage near Nevada, MO (USGS06918060) were used to estimate the 7Q10 flows. The 7Q10 flow estimated from the gages was distributed to the boundaries and inflow points of the model domain according to the proportion in drainage area. The 7Q10 flows are 0.4 cfs and 2.8 cfs for the upstream and downstream boundaries, respectively.

Ecoregion values were used for the nutrient loadings of the model run. For the Central Irregular Plains Level III Ecoregion, the nutrient values are 0.855 mg/l for TN, 0.092 mg/l for TP, and 2.8 ug/l for Chlorophyll-A. At the upstream model boundary, recent water quality data (summer period) from the monitoring station (SC208) near Fort Scott, KS were used.

Using the ecoregion nutrient loadings, simulation results shows an average SOD reduction of 60% is required in Marmaton River in order to meet the DO standard. The simulated longitudinal profile of DO corresponding to 60% SOD reduction shows that beginning from the KS-MO state line (about 56 km) up to the downstream boundary, the simulated minimum DO is equal to or greater than 5 mg/L.

In order to meet the DO WQS downstream of the confluence of Little Drywood Creek and Marmaton River, a $CBOD_5$ loading of 2.0 mg/l was assumed for Little Drywood Creek. The assumption is consistent with MoDNR data for August, 2008 from a site 2.4 mi upstream of the confluence and downstream of the Nevada WWTP. To meet the required loading of 2 mg/l at the confluence, the $CBOD_5$ loading from the Nevada WWTP needs to be reduced to 7.75 mg/l. This $CBOD_5$ limit was obtained through a QUAL2k model for a 2.9 mi. segment of Little Drywood Creek (segment from just upstream of the Nevada WWTP to the confluence with Marmaton River). Simulation was performed using the design flow of the WWTP and 7Q10 flow for the segment.

Table 3. Comparison of model predicted and simulated DO.

	Site 1		Site 2		Site 3	
	Data	**Model**	**Data**	**Model**	**Data**	**Model**
Marmaton Dissolved Oxygen, mg/L						
Minimum	4.47	4.43	4.14	4.01	4.47	4.24
Error (%)	*-0.04 (-1.0%)*		*-0.13 (-3.1%)*		*-0.23 (-5.1%)*	
Maximum	7.25	7.32	5.48	5.73	5.92	6.37
Error (%)	*0.07 (1.0%)*		*0.25 (4.6%)*		*0.45 (7.6%)*	
Mean	5.65	5.66	4.66	4.73	5.05	5.07
Error (%)	*0.01 (0.2%)*		*0.07 (1.5%)*		*0.02 (0.4%)*	

Table 4. Water quality data from KDHE monitoring site SC208 (near Fort Scott, KS)

Date	Time	Flow* cfs	DO mg/l	BOD_5 mg/l	NH_3 mg/l	NO_3 mg/l	TKN mg/l	OrthoP mg/l	TP mg/l	TSS mg/l	TOC mg/l
6/7/2000	0925	1.9	5.0	7.11	0.020	0.650	1.380	0.02	0.220	71	
7/6/2000	1305	19	5.7	3.21	0.020	0.700	1.170	0.02	0.140	48	
8/9/2000	0910	3.2	3.9	3.33	0.020	0.120	0.900	0.02	0.140	40	
9/7/2000	1130	0	2.2	3.24	0.086	0.170	1.260	0.02	0.110	20	
7/11/2001	0945	8.2	4.3	2.34	0.020	0.080	0.555	0.02	0.208	64	11.070
9/6/2001	0925	0.7	4.0	3.60	0.033	0.090	1.253	0.02	0.179	50	7.720
6/5/2002	1148	124	6.3	***0.65*****	0.269	0.330	1.074	0.25	0.153	56	3.890
8/7/2002	0944	0.29	3.7	***2.13***	0.100	0.100	1.429	0.25	0.187	47	7.512
7/9/2003	0859	0.8	4.1	***1.04***	0.100	0.100	1.122	0.25	0.129	27	4.856
9/10/2003	0914	7.4	5.1	***0.91***	0.100	1.050	1.155	0.25	0.236	67	4.538
6/9/2004	0846	14	4.5	***1.32***	0.100	0.430	0.554	0.25	0.165	51	5.523
8/4/2004	0905	19	6.0	***1.19***	0.100	0.470	0.475	0.25	0.170	38	5.218
7/13/2005	0857	5.2	4.5	***2.17***	0.100	0.420	0.509	0.25	0.135	38	7.594
9/14/2005	0854	7.2	4.6	***1.18***	0.100	0.530	0.814	0.25	0.090	37	5.195
6/7/2006	1008	11	5.4	***1.10***	0.100	0.180	0.574	0.25	0.113	35	4.985
8/9/2006	0931	5.4	4.0	***1.16***	0.120	0.950	0.943	0.25	0.098	22	5.147
7/11/2007	0809	151	6.6	***0.85***	0.100	0.200	0.664	0.25	0.109	38	4.375
9/12/2007	0812	11	6.7	***1.48***	0.100	0.100	0.589	0.25	0.161	51	5.913
6/4/2008	0828	333	7.3	***1.56***	0.100	0.350	0.853	0.25	0.152	51	6.100
8/6/2008	0834	18	5.6	***1.62***	1.077	0.480	1.923	0.25	0.215	25	6.268
7/21/2009	0930		6.6	***0.70***	0.100	0.879	0.749	0.25	0.132	75	4.026

* flow at the USGS gage near Marmaton, KS.

** estimated using relationship with TOC developed by KDHE (BOD_5=-0.946+0.4103*TOC)

VI. References

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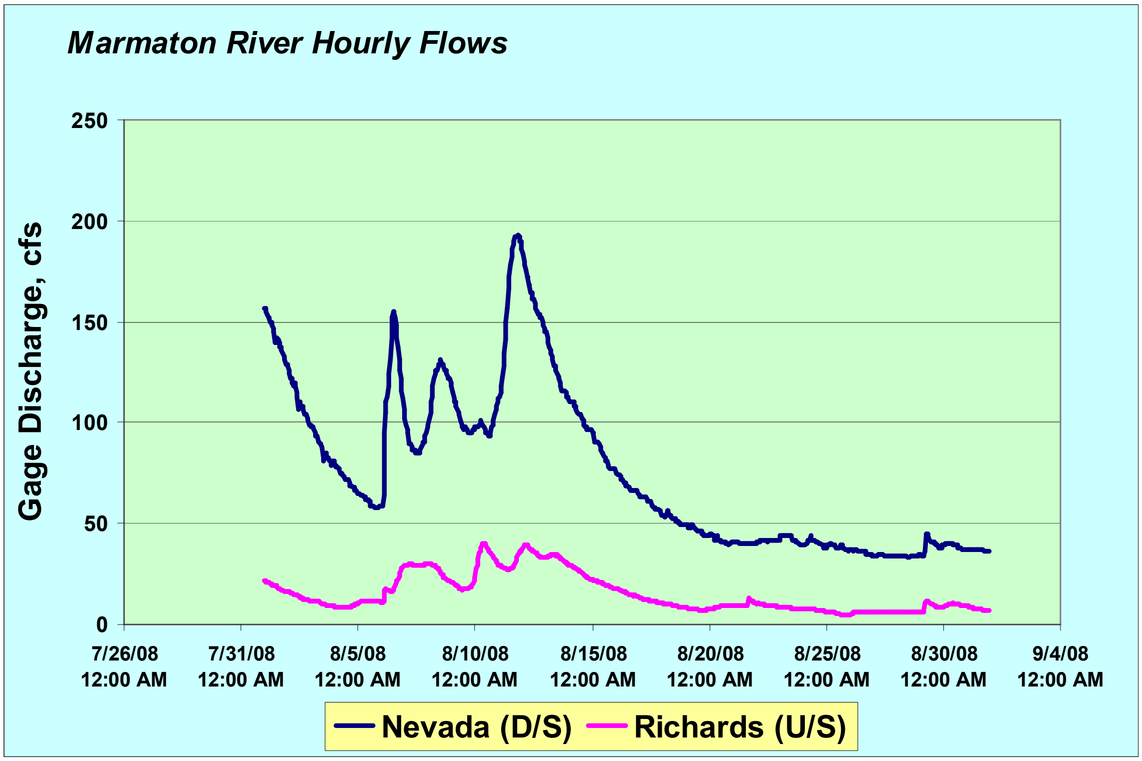


Figure 1. Hourly flows at the USGS gages near Richards, MO and Nevada, MO.

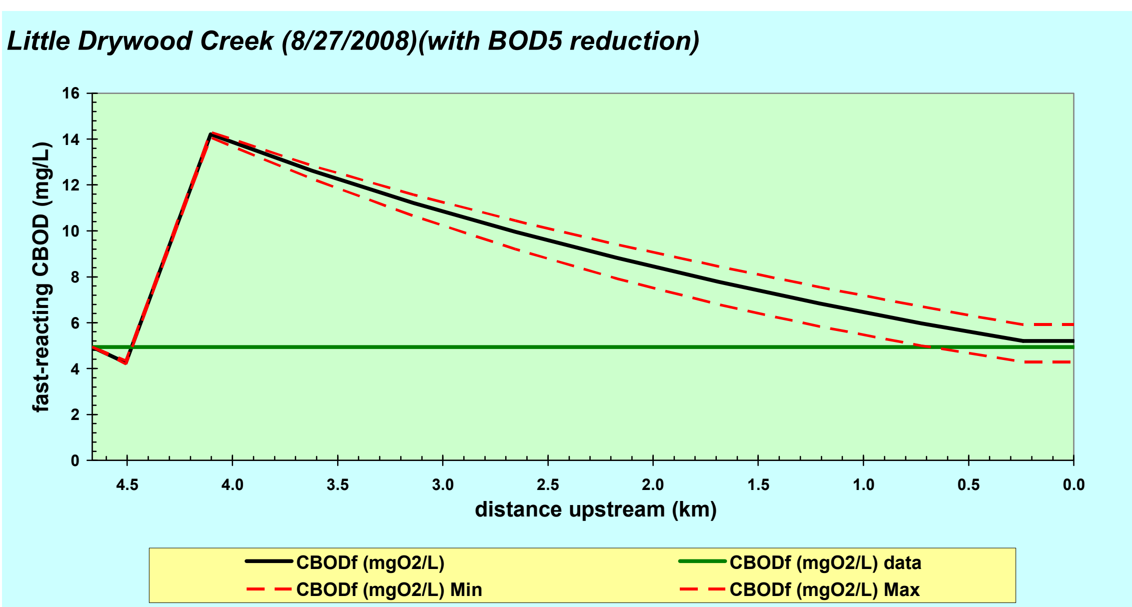


Figure 2. Model predicted longitudinal variation in CBOD in the Little Drywood Creek.

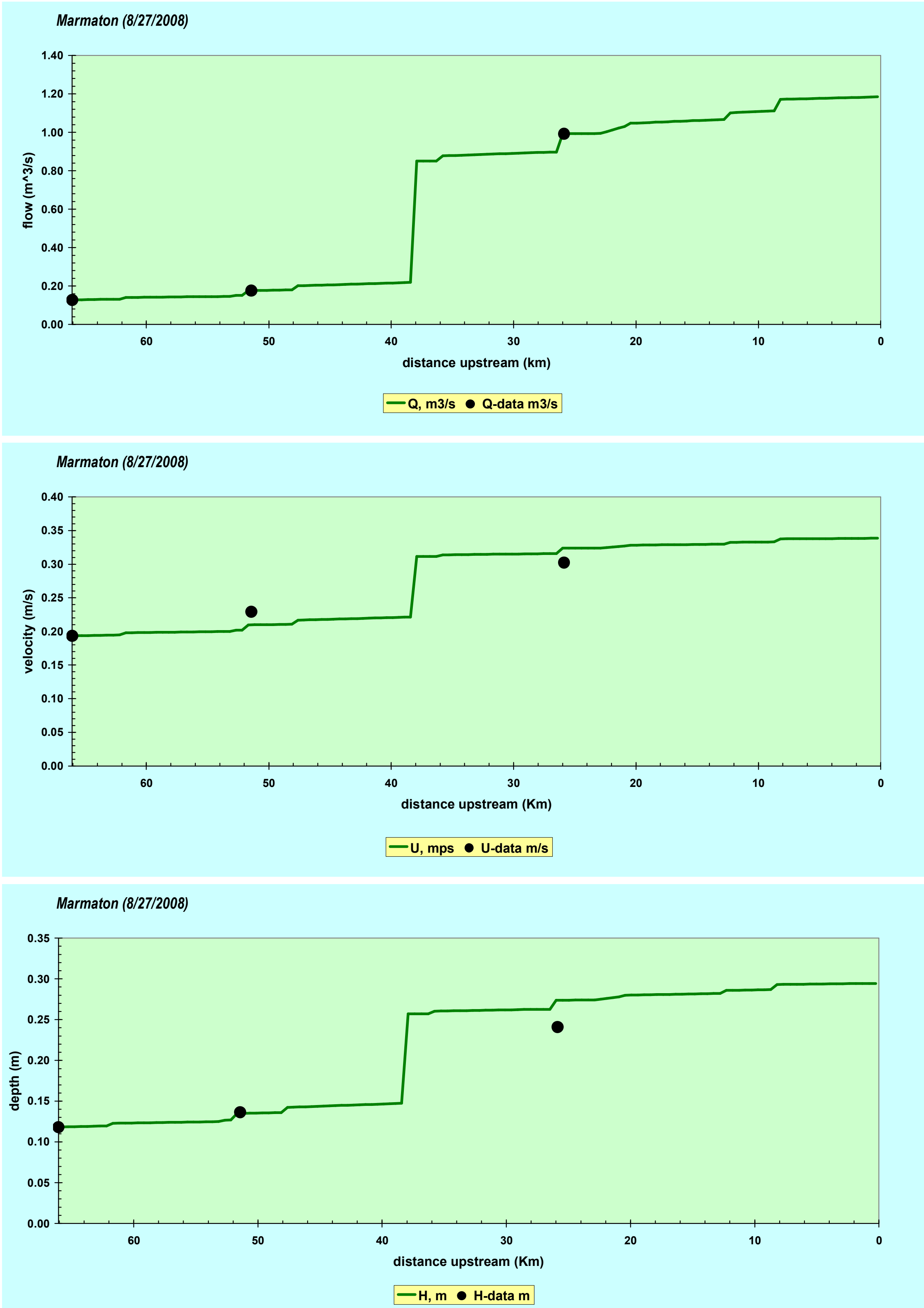
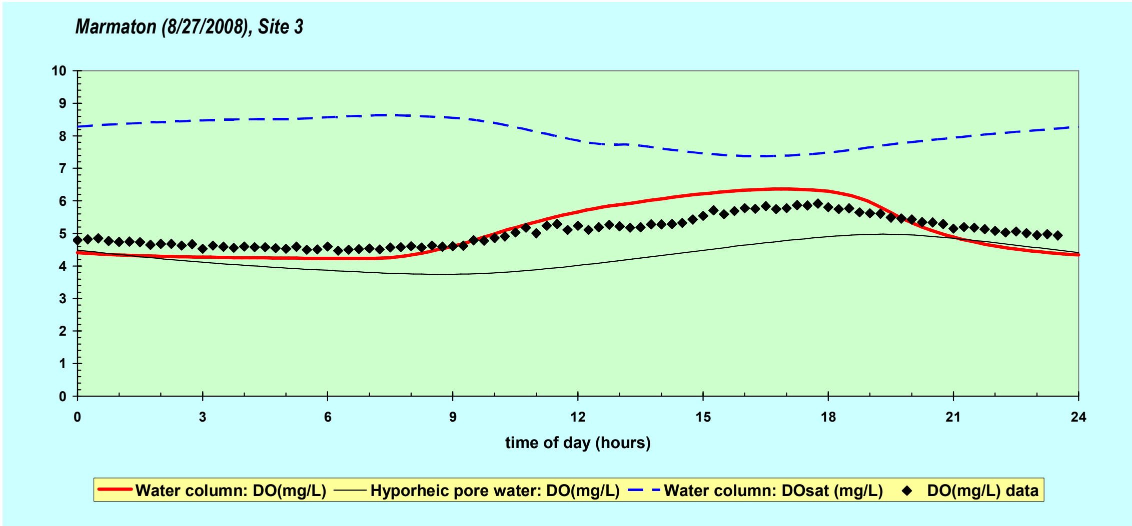
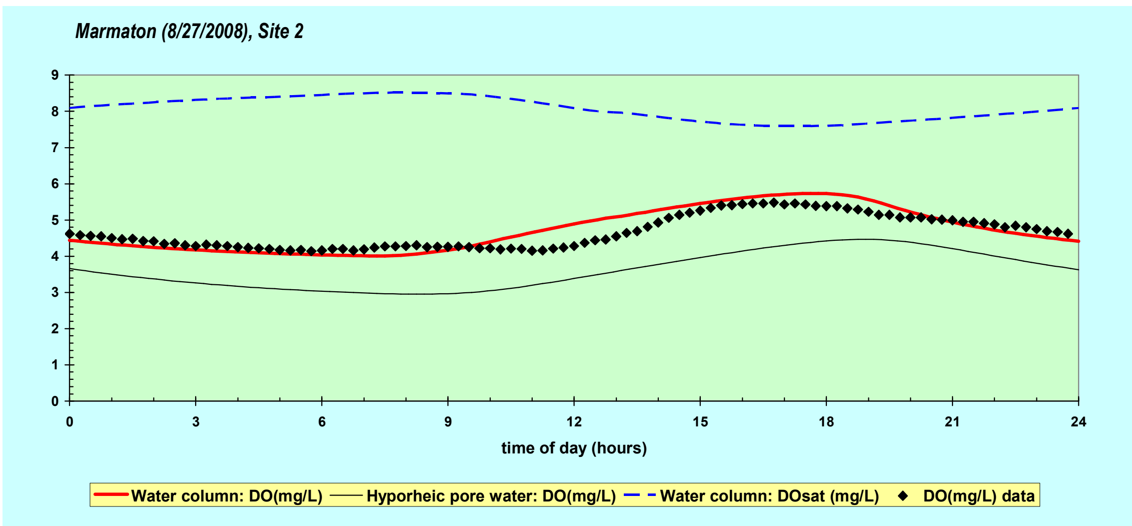


Figure 3. Measured and predicted flow, depths and velocities for Marmaton River.





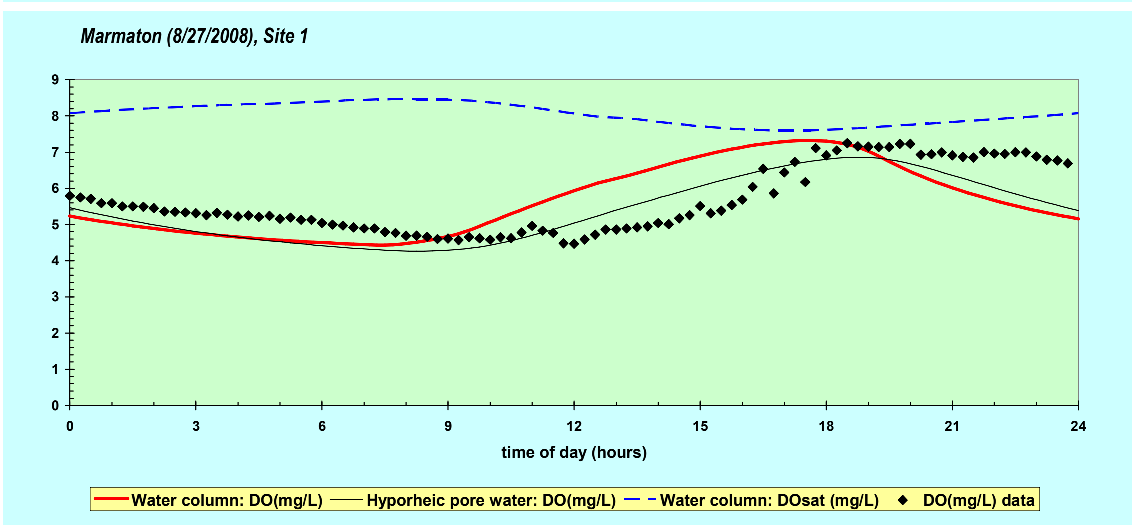


Figure 4. Comparison of measured and model predicted DO for Marmaton sites.

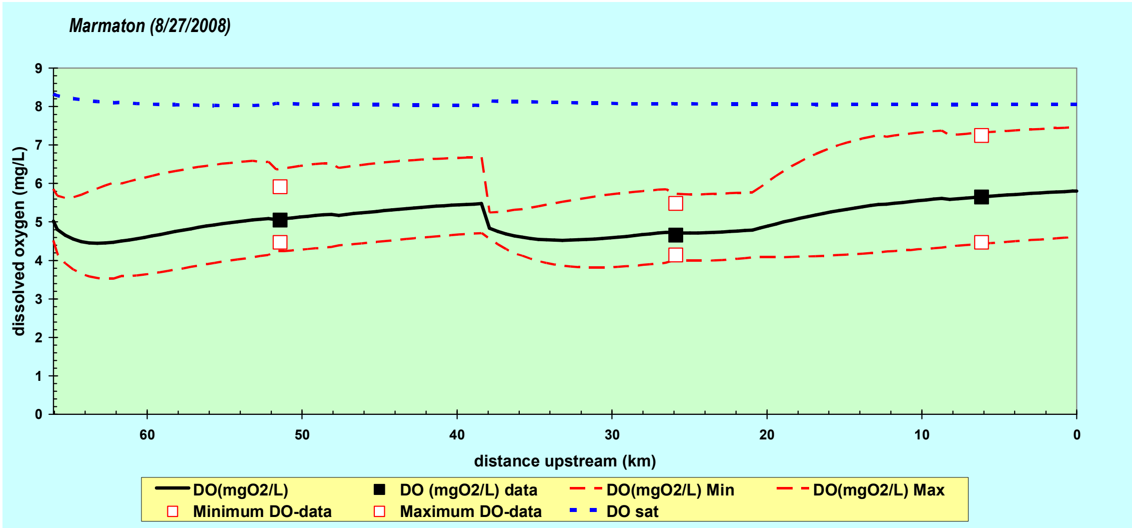


Figure 5. Model predicted longitudinal variation in DO in Marmaton River.

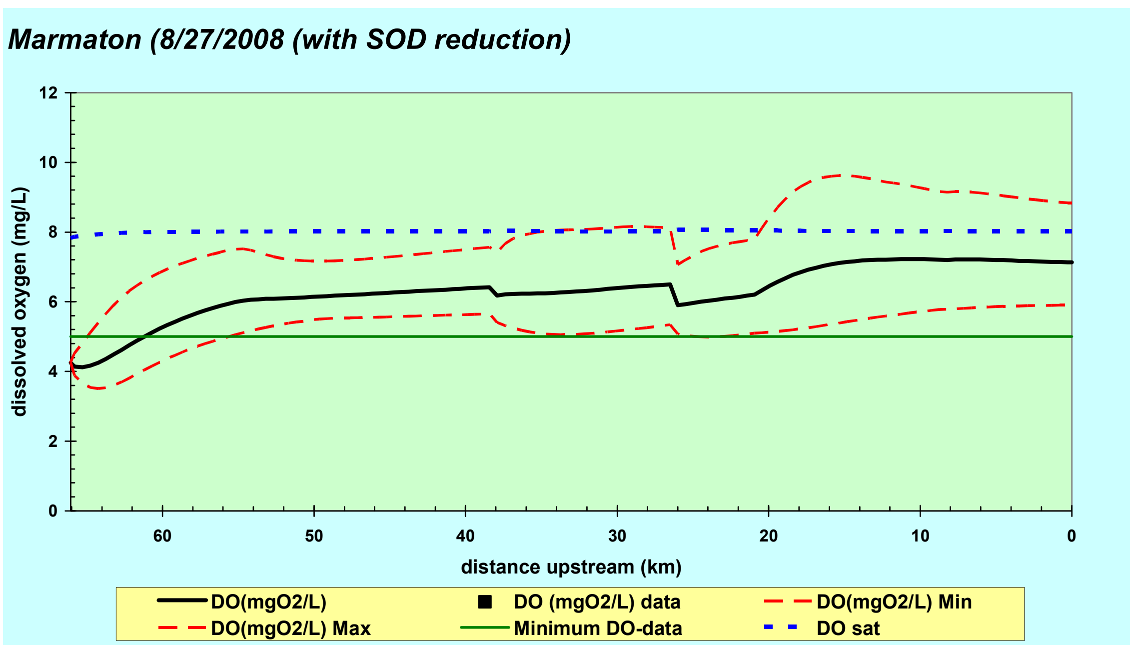


Figure 6. Model predicted longitudinal variation in DO in the Marmaton River with ecoregion nutrient loadings and reduction in SOD.